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TRANSACTIONS

of the
**American Society
for Steel Treating**

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TRANSACTIONS

American Society for Steel Treating

VOL. XV

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NO. 3

HIGH CARBON HIGH CHROMIUM STEELS

BY J. P. GILL.

Abstract

The author compares the properties of six steels of the high carbon, high chromium class, which, during recent years, have become so popular as die steels. The comparison covers the critical points, hardening and tempering curves, microstructure and physical properties. A short discussion of the constitution of steels of this class is also included; also a brief historical outline of the development of steels of this type.

HISTORICAL

THE metal chromium was discovered in 1797 by Vauquelin and was named chromium from the word "croma" meaning color, due to the many colors imparted to minerals by its oxides. The first experiments made in reference to the addition of chromium to iron and steel were by Faraday and Stodart in 1820. Berthier followed with other experiments in 1821 which were much more exhaustive than Faraday's. The first commercial application of the addition of chromium to steel was made by Robert Mushet in 1861. Shortly afterwards, in 1865, Julius Baur of New York was granted an American patent on a chromium steel. Brustlein made a number of interesting experiments in reference to the addition of chromium to steel beginning in 1876. The subject, in general, of the effect of chromium in iron and steel was most fully covered in a paper read before the Iron and Steel Institute of Great Britain

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. The author, J. P. Gill, a member of the society, is chief metallurgist with the Vanadium-Alloys Steel Co., Latrobe, Pa. Manuscript received July 9, 1928.

by Sir Robert Hadfield in 1892. In his paper¹ he touches slightly on high carbon, high chromium steels, concerning which he says, "As will be seen . . . samples have been obtained containing as high as 16.74 per cent chromium but this material is only partially malleable. Probably this is owing to the carbon (2.12 per cent) being so high. Specimen 'N' (15.12 per cent chromium) was by careful treatment sufficiently malleable to obtain test bars but this is about the limit of forgeability, at any rate in the presence of the unavoidable amount of carbon 1.79 per cent. (Hadfield apparently was trying to obtain high chromium steels low in carbon but was unable to do so, because of the high carbon content of the ferrochromium used.) 'N' (1.79 per cent carbon, 15.12 per cent chromium) and 'O' (2.12 per cent carbon and 16.74 per cent chromium) show but little change by annealing. Before this treatment they are hard and seem to possess somewhat of the nature of badly chilled cast iron . . . 'N' cracked badly when forged but sufficient material was obtained to make a test bar. Ingot 'O' would not, however, either forge at a medium or low heat and sample 'M' (1.27 per cent carbon and 11.13 per cent chromium) may be taken as the highest limit of forgeability . . ." A few other unimportant properties of high carbon, high chromium steels were mentioned in his exhaustive paper. After 1900 the number of investigators experimenting with chromium steels increased rapidly and the writer has been unable to learn the approximate time of the first commercial applications of steels containing high carbon and high chromium. Messrs. Patch and Furness applied for a patent in 1915, which was granted in 1916 relating to the invention of a steel containing from 15.00 to 20.00 per cent chromium and from 1.0 to 2.0 per cent carbon. In their patent application, however, they state that previously they believed that it had only been proposed to use chromium between 12.00 and 16.00 per cent with carbon above 2.00 per cent, thus recognizing the existence and use of high carbon, high chromium steels previous to the time of their application for a patent. Steels for drawing dies with a high carbon (1.50-2.50 per cent) and a high chromium content, others with a high tungsten content had been used for a number of years previous to this time (1916). In the patent of Patch and Furness, stress is made of the fact that their steel is a

¹The figures appearing in parentheses refer to the bibliography appended to this paper.

nondeforming tool steel and that it has the advantage of an increase in the life of the tool and the capacity to cut at higher speeds. An English patent was granted to P. R. Kuehnrich in 1918, application for which was filed in 1916, which related to a steel containing approximately 1.50 per cent carbon, 12.00 per cent chromium and 3.50 per cent cobalt. The patent application states that the object was to provide a substitute for high speed steel by the addition of cobalt to carbon-chromium steels and that steel covered by his invention possessed the characteristic property of "red hardness," etc. In England during the World War high carbon, high chromium steels were used to a certain extent to replace high speed steel for cutting operations, which steels were known as "tungstenless" high speed steels. During the last several years high carbon, high chromium steels have become increasingly popular with American manufacturers for a wide range of tools. The one property of high carbon, high chromium steels which had made it so popular is its high resistance to abrasion or wear, yet little or no mention is made of this one outstanding property in the literature previous to 1920. The earlier applications of high carbon, high chromium steels (excepting drawing dies) seem to have been for cutting tools of the nature of lathe tools, taps, etc., while during the last several years the steel has widely appealed to manufacturers more as a die steel and there is no doubt but that steels of this type will be more widely used in the future.

COMPOSITIONS STUDIED

The present paper deals with a comparison of six types of high carbon, high chromium steels, the composition of which will be found in Table I.

CONSTITUTION

A search of the literature on the constitution of chromium steels reveals a large number of articles and papers treating with this phase in particular. Excellent papers have been published by Murakami (2), Grossmann (5) and others. Murakami suggests chemical formulæ for the carbides of high carbon, high chromium steels, as well as discussing the constitution of the matrix, while Grossmann has given us a detailed development of the constitutional diagram.

The writer has only briefly studied this interesting subject and

Table I
Chemical Composition of Steels Studied with Compositions of Residues

Steel	Wt. taken, grams	Average wt. residue obtained, grams	Per Cent									
			C	Si	Mn	S	P	Cr	V	Co	Ni	Mo
A			2.38	0.42	0.71	0.010	0.030	12.48				
Residue B	5	0.85	7.77					37.73	0.00	0.00	0.24	0.00
Residue C	5	0.73	2.12	0.24	0.31	0.020	0.021	13.20	0.81	0.00	0.12	0.00
Residue D	5	0.20	7.39	0.35	0.26	0.006	0.015	41.75	1.12			
Residue E	5	0.65	1.38					12.20	0.00	3.45	0.00	0.54
Residue F	5		7.60					46.75		0.40		4.30
Residue G	5	0.51	2.17	0.19	0.46	0.009	0.015	13.43	0.00	0.00	0.51	0.00
Residue H	5		7.59	0.09	0.30	0.011	0.026	16.95			0.41	
Residue I	5	0.40	1.60					41.43	0.00	0.00	0.31	0.00
Residue J	5		7.84					55.04				
Residue K	5		2.19	0.24	0.39	0.012	0.018	12.01	0.72	0.66	0.00	0.00
Residue L	5		7.76					35.12	2.35	0.19		

a preliminary investigation of this phase was made of only one of the steels studied, namely, Steel "H." The structures of the ingot as cast are shown in photomicrographs Figs. 1 to 3. The photomicrographs were made near both the outside and center of the ingot as well as half-way between. The structure as shown is characterized by a heavy chromium segregate of eutectic composition. The segregates are surrounded or embedded in a poorly defined matrix rich in dissolved chromium and carbon. No evidence was developed through the use of different etching reagents to indicate that the eutectic as shown in the cast structure varied in chemical composition. There is no evidence of graphitic carbon in the cast structure. Upon annealing the ingot as cast a large number of very small chromium carbides are precipitated which probably differ somewhat in chemical composition from the eutectic segregate. Photomicrographs Figs. 4 to 6 are of the annealed ingot. After breaking up the segregate by mechanical work it will again fuse together at temperatures below the melting point of the steel as shown in photomicrographs Figs. 27 to 30.

There is evidence that the high carbon, high chromium steels studied are composed essentially of a matrix rich in dissolved chromium, carbon and chromium carbides with a eutectic segregate and a precipitated chromium carbide, which carbides are precipitated on slow cooling from casting or on reheating the steel after

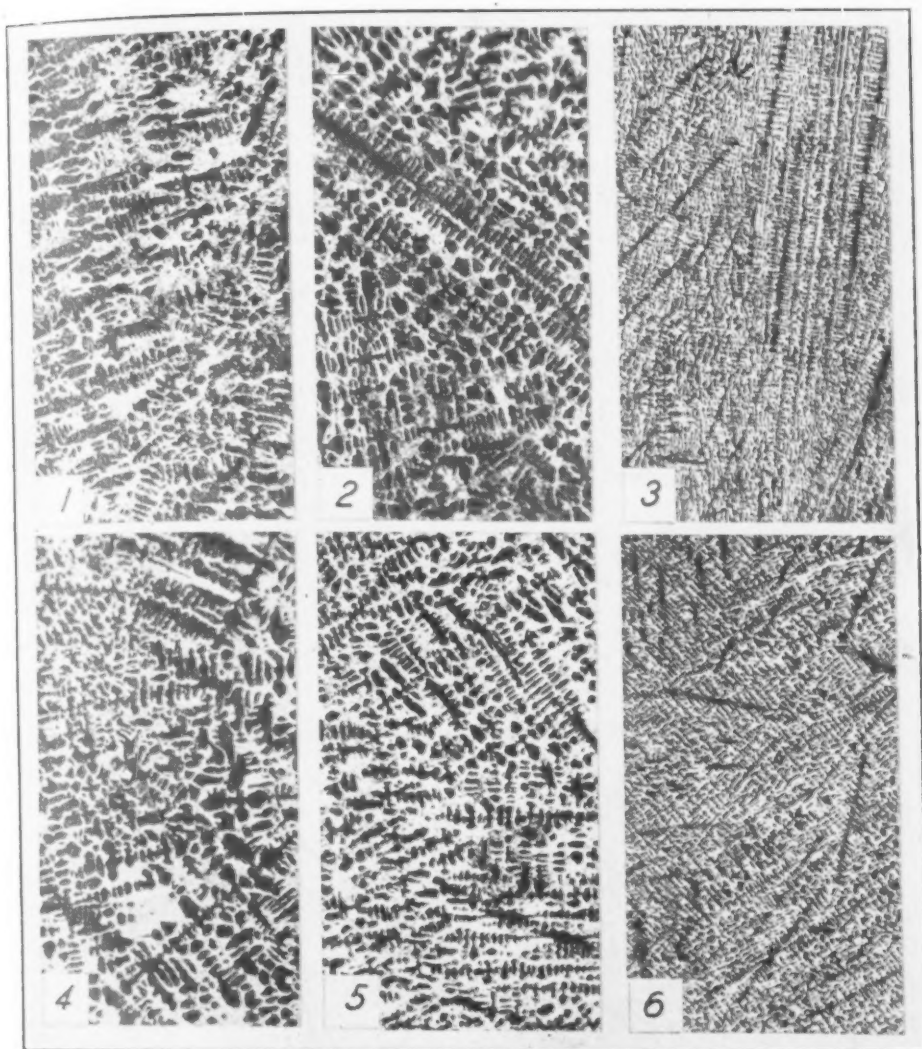


Fig. 1—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot. Specimen Taken at Center of Ingot. Fig. 2—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot. Specimen Taken Half Way Between Center and Outside. Fig. 3—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot. Specimen Taken $\frac{1}{4}$ -Inch from Surface. Fig. 4—Photomicrograph Showing Steel H. Same as No. 1 Except Annealed. Fig. 5—Photomicrograph Showing Steel H. Same as No. 2 Except Annealed. Fig. 6—Photomicrograph Showing Steel H. Same as No. 3 Except Annealed. All Photomicrographs $\times 16$.

casting; the amount of precipitated carbide depending on the treatment.

An analysis of the segregate and carbides was made of the six steels studied, by dissolving annealed samples slowly in dilute hydrochloric acid, the residue remaining being taken as constituting the segregates and carbides. The results are shown in Table I. Although the carbon content of the six steels in question varies

Residues

Ni	Mo
0.24	0.00
0.12	0.00
0.00	0.54
0.51	4.30
0.41	0.00
0.31	0.00
0.00	0.00

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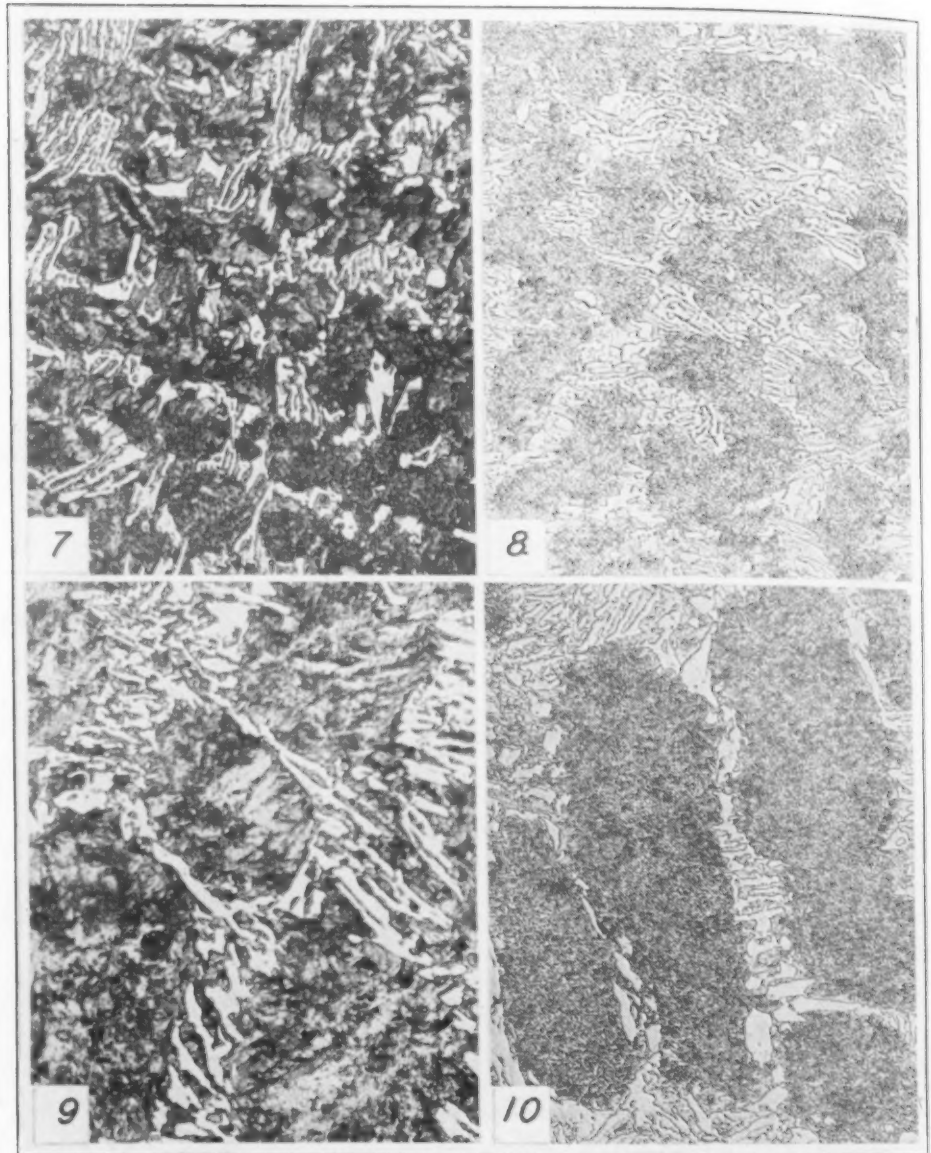


Fig. 7—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot. Specimen Taken $\frac{1}{4}$ -Inch From Surface. Fig. 8—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot, and Annealed. Specimen Taken $\frac{1}{4}$ -Inch From Surface. Fig. 9—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot. Specimen Taken $\frac{1}{2}$ Distance From Center to Outside. Fig. 10—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot, and Annealed. Specimen Taken $\frac{1}{2}$ Distance From Center to Outside. All Photomicrographs $\times 350$.

from 1.60 to 2.40 per cent, yet the carbon content of the residues is within quite narrow limits. The chromium content likewise covers a fairly narrow range, excepting for steel "E" which had a chromium content of approximately 4.00 per cent in excess of the

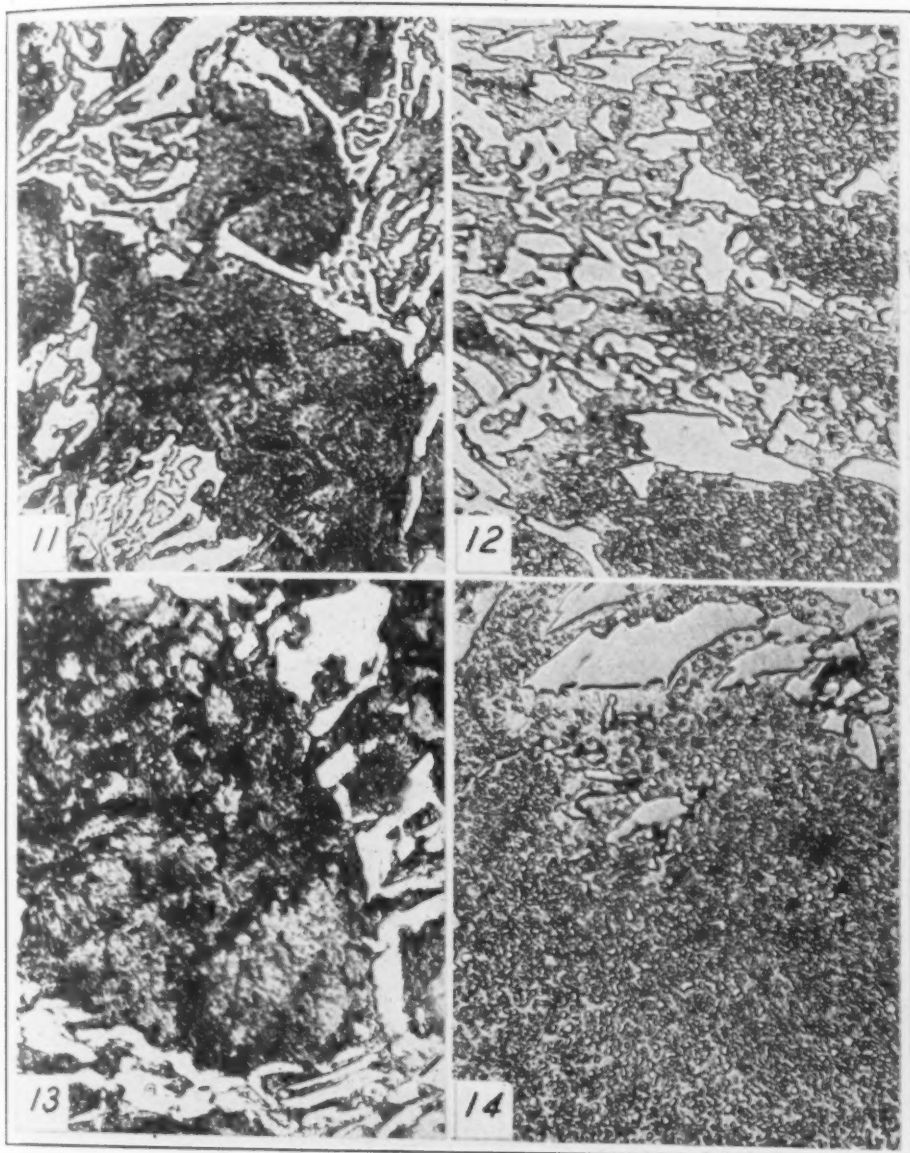


Fig. 11—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot. Specimen Taken $\frac{1}{4}$ -Inch From Surface. Fig. 12—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot and Annealed. Specimen Taken $\frac{1}{4}$ -Inch From Surface. Fig. 13—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot. Specimen Taken Half Way Between Center and Outside. Fig. 14—Photomicrograph Showing Steel H. As Cast Into 6-Inch Ingot and Annealed. Specimen Taken Half Way Between Center and Outside. All Photomicrographs $\times 1000$.

other five steels, and therefore, shows a much greater percentage of chromium in the segregate. Of the two steels containing vanadium it is found that approximately twice the amount of vanadium is found in the segregate of steel "H" as is found in the segre-

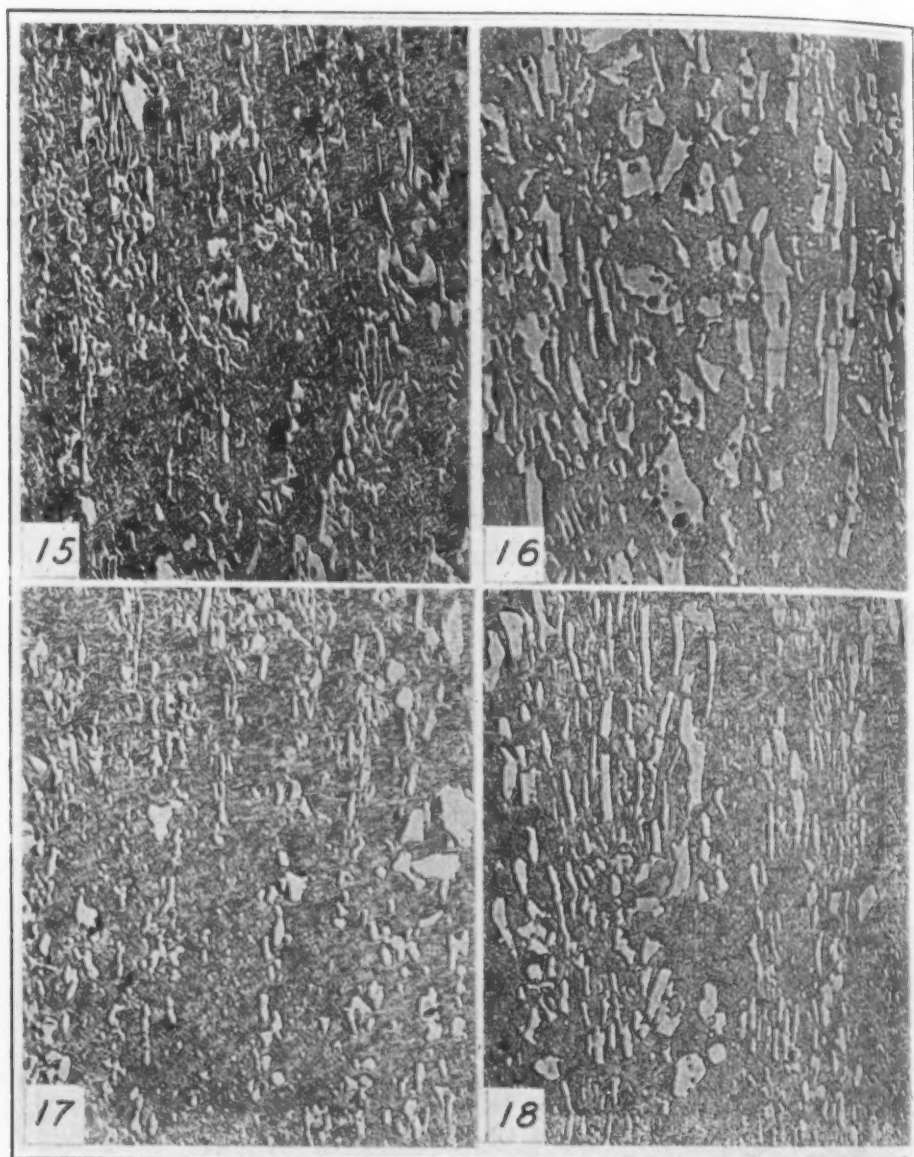


Fig. 15—Photomicrograph Showing Steel A. Longitudinal Section 4-Inch Billet. Specimen Taken $\frac{1}{4}$ -Inch From Surface. Fig. 16—Photomicrograph Showing Steel A. Longitudinal Section 4-Inch Billet. Specimen Taken Half Way Between Center and Outside. Fig. 17—Photomicrograph Showing Steel B. Longitudinal Section 4-Inch Billet. Specimen Taken $\frac{1}{4}$ -Inch From Surface. Fig. 18—Photomicrograph Showing Steel B. Longitudinal Section 4-Inch Billet. Specimen Taken One-Half Distance From Center to Outside. All Photomicrographs $\times 250$.

gate of steel "B"; as to whether or not this is due to the cobalt content of steel "H" is problematical. Cobalt and nickel are usually dissolved by iron and are not considered as carbide formers, and as would be expected in steel "C" containing 3.50 per

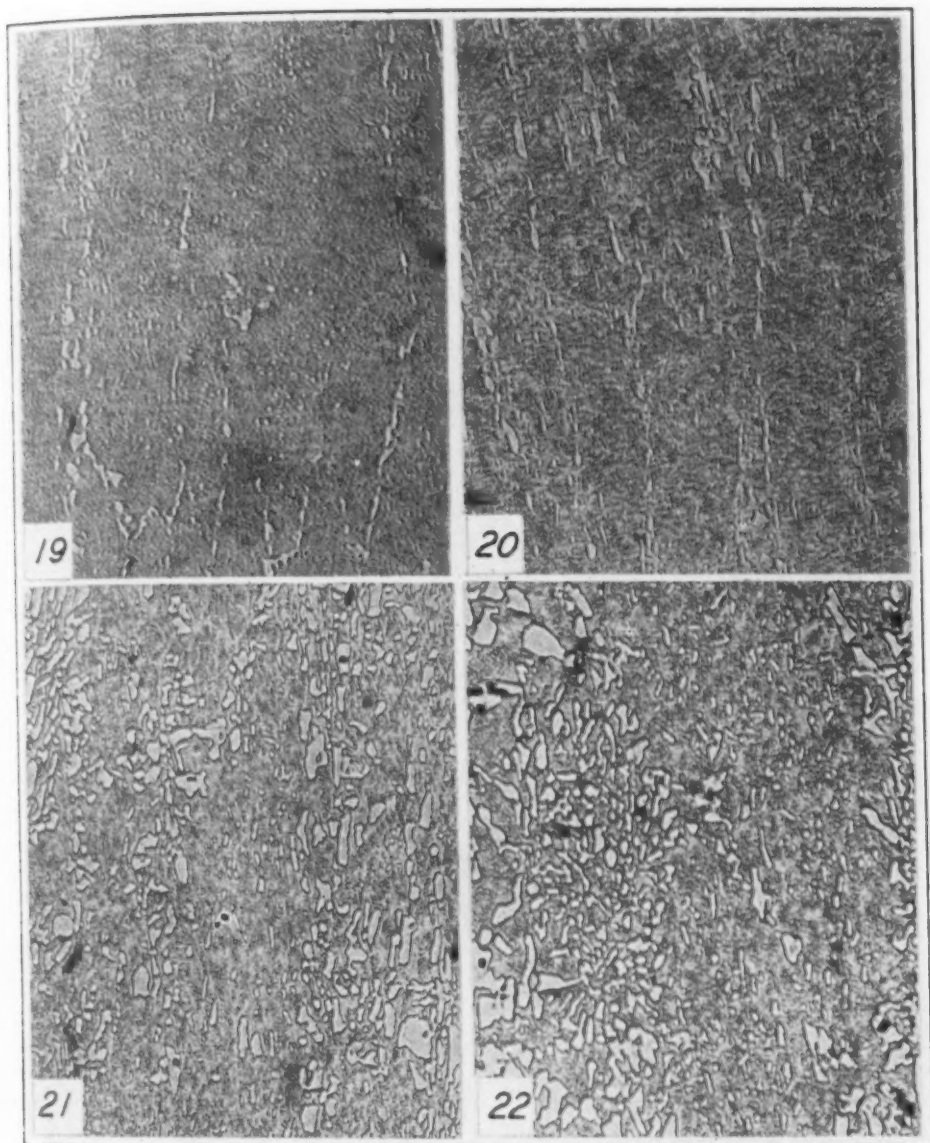


Fig. 19—Photomicrograph Showing Steel C, 4-Inch Billet, Longitudinal Section, Photograph Taken $\frac{1}{4}$ -Inch from Surface. Fig. 20—Photomicrograph Showing Steel C, 4-Inch Billet, Longitudinal Section, Photograph Taken One-Half Distance from Center to Outside. Fig. 21—Photomicrograph Showing Steel D, 4-Inch Billet, Longitudinal Section, Photograph Taken $\frac{1}{4}$ -Inch from Surface. Fig. 22—Photomicrograph Showing Steel D, 4-Inch Billet, Longitudinal Section, Photograph Taken One-Half Distance from the Center to Outside. All Photomicrographs $\times 250$.

Billet. Specimen Taken Longitudinal Section. All Photo-

the cobalt nickel are carbide forming 3.50 per

cent cobalt, only 0.40 per cent was found in the residue; but it is difficult to explain why 0.41 per cent nickel was found in the residue of steel "D," which steel actually only contained 0.51 per cent nickel.

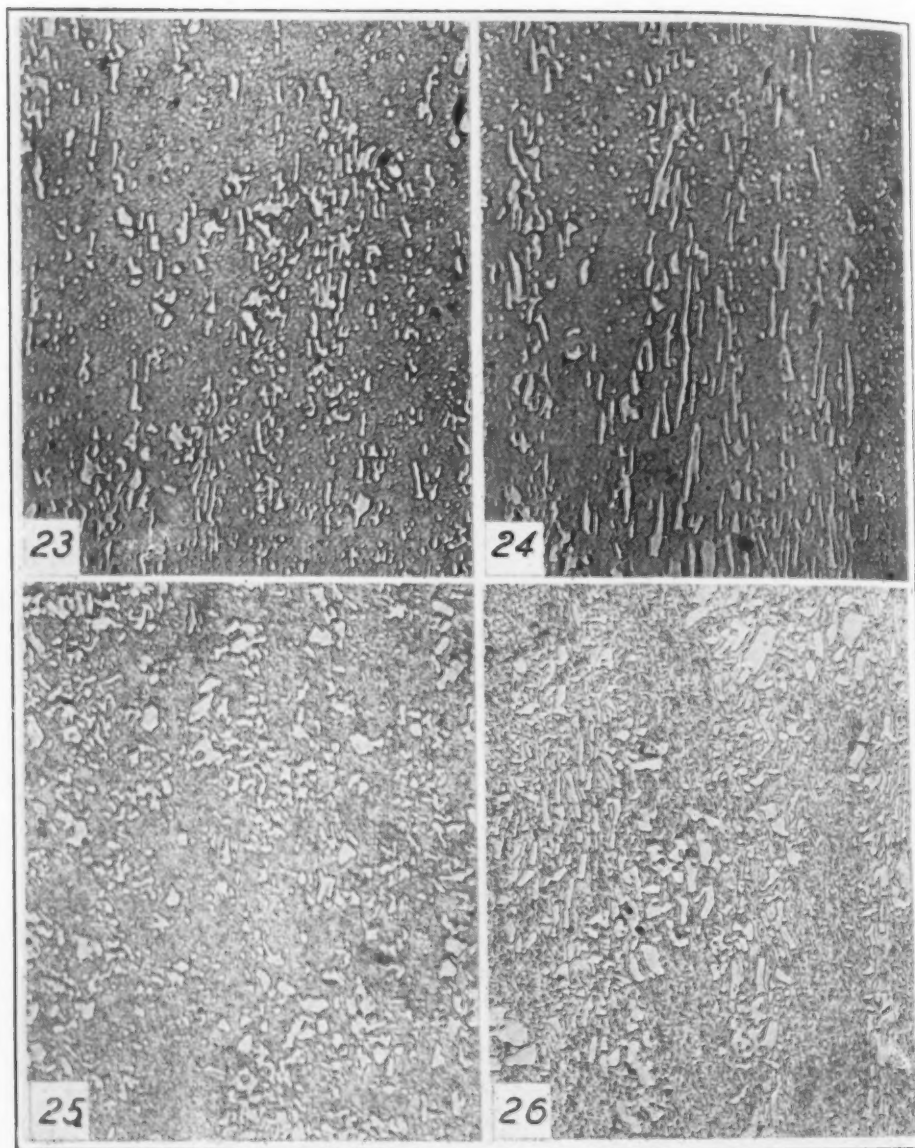


Fig. 23—Photomicrograph Showing Steel E. 4-Inch Billet. Longitudinal Section. Photograph Taken $\frac{1}{4}$ -Inch from Surface. Fig. 24—Photomicrograph Showing Steel E. 4-Inch Billet. Longitudinal Section. Photograph Taken One-Half Distance from Center to Outside. Fig. 25—Photomicrograph Showing Steel H. 4-Inch Billet. Longitudinal Section. Photograph Taken $\frac{1}{4}$ -Inch from Surface. Fig. 26—Photomicrograph Showing Steel H. 4-Inch Billet. Longitudinal Section. Photograph Taken One-Half Distance from Center to Outside. All Photomicrographs $\times 250$.

It is interesting to note that the two residues of least weight were obtained from the two steels containing cobalt, namely, steels "C" and "H." Of the steels containing carbon and chromium without appreciable amounts of cobalt or vanadium, the amount

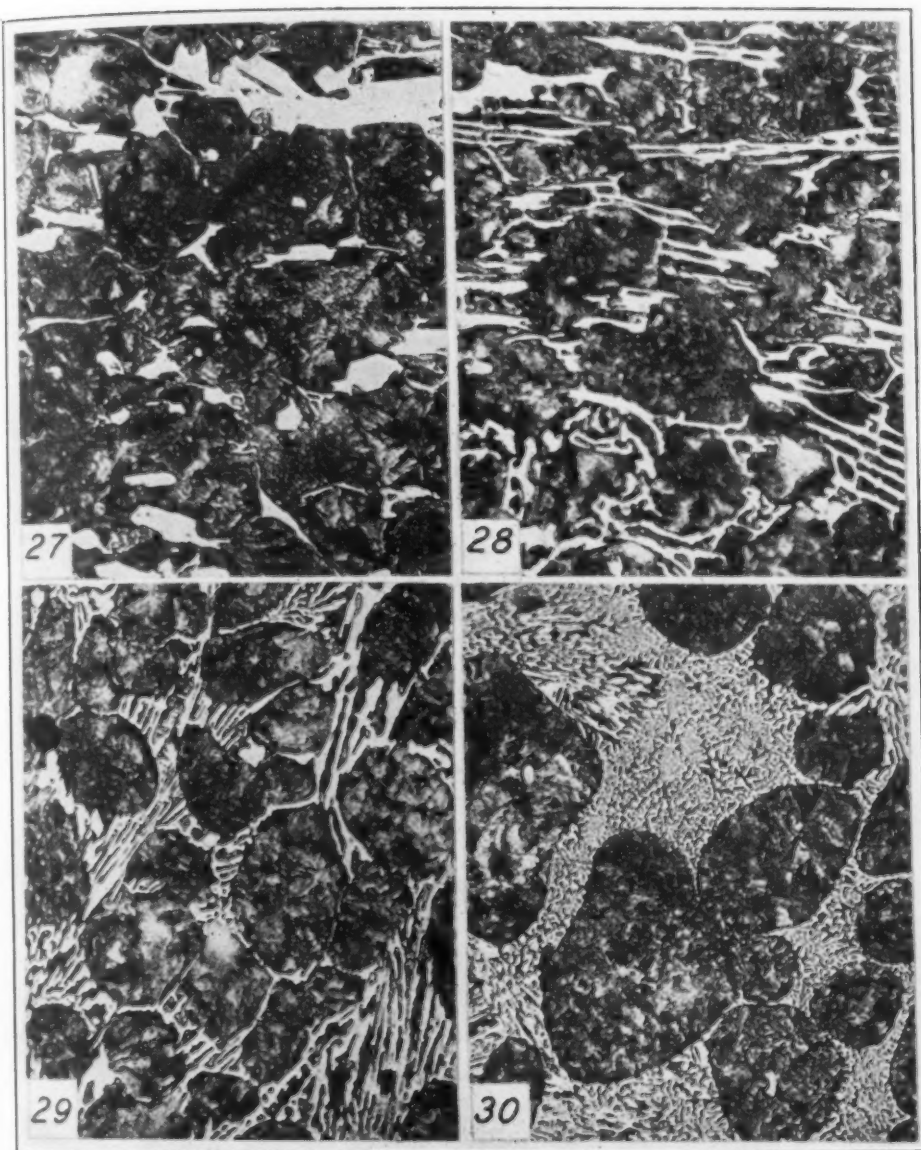


Fig. 27—Photomicrograph Showing Steel H. Showing the Progressive Fusion of the Eutectic. Specimens Taken from $\frac{3}{4}$ -Inch Square Forged Bar. Fig. 28—Photomicrograph Showing Steel H. Showing the Progressive Fusion of the Eutectic. Specimens Taken from $\frac{3}{4}$ -Inch Square Forged Bar. Fig. 29—Photomicrograph Showing Steel H. Showing the Progressive Fusion of the Eutectic. Specimens Taken from $\frac{3}{4}$ -Inch Square Forged Bar. Fig. 30—Photomicrograph Showing Steel H. Showing the Progressive Fusion of the Eutectic. Specimens Taken from $\frac{3}{4}$ -Inch Square Forged Bar. All Photomicrographs $\times 500$.

of carbide and eutectic is more dependent on the carbon content than the chromium content.

Photomicrographs Figs. 15 to 26 show the longitudinal structures of 4-inch billets fully annealed; one photomicrograph taken

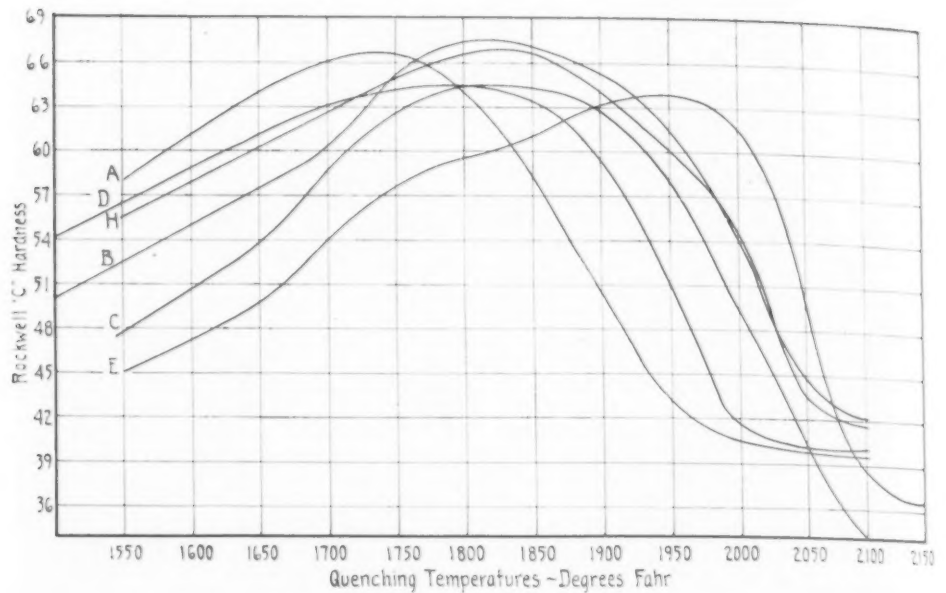


Fig. 31—Rockwell C Hardness Vs. Quenching Temperature Curves for Steels Studied.

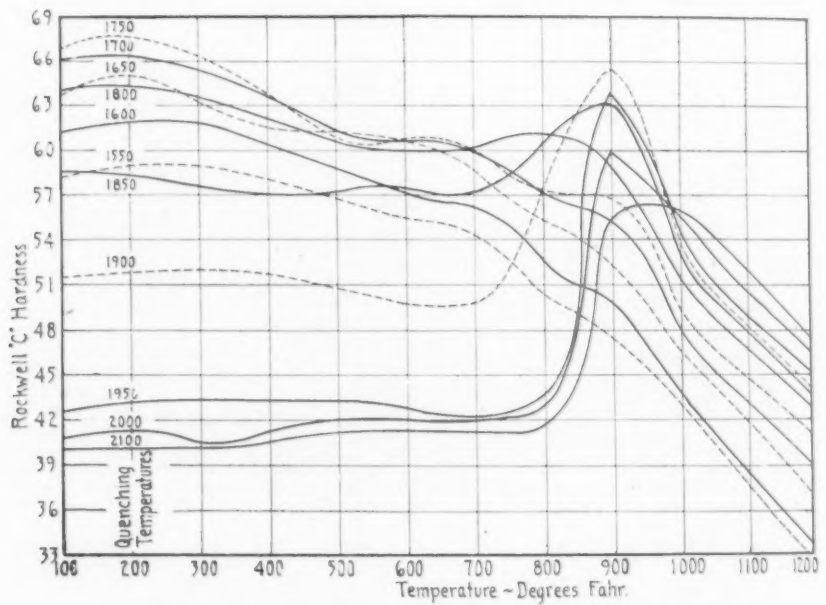


Fig. 32—Rockwell Hardness Vs. Tempering Temperature Curves for Steel A. Quenched at Various Temperatures.

near the surface and the other midway between the surface and center. The least amount of eutectic segregate is found in steels "C" and "E" because of lower carbon content. The segregate is largest and least broken up in steel "A" which is essentially a

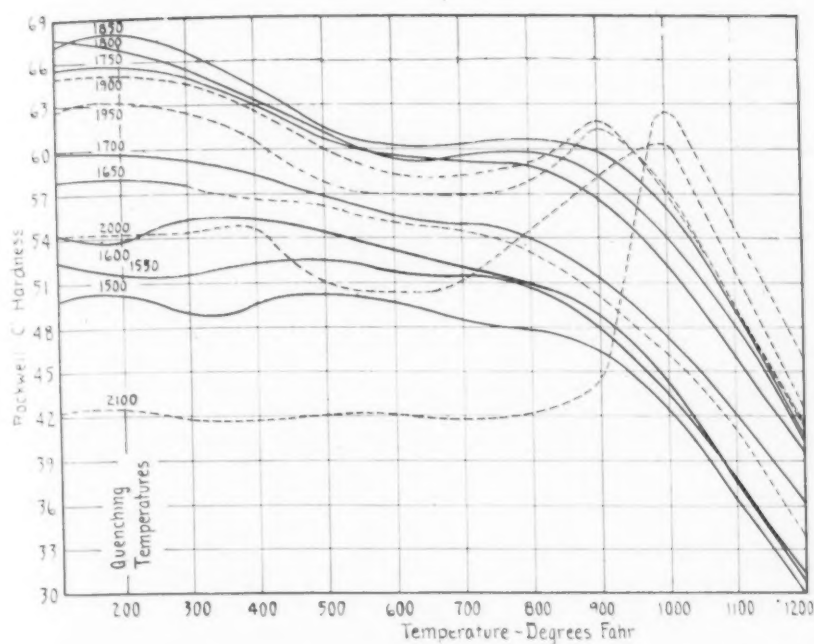


Fig. 33—Rockwell Hardness Vs. Tempering Temperature Curves for Steel B. Quenched at Various Temperatures.

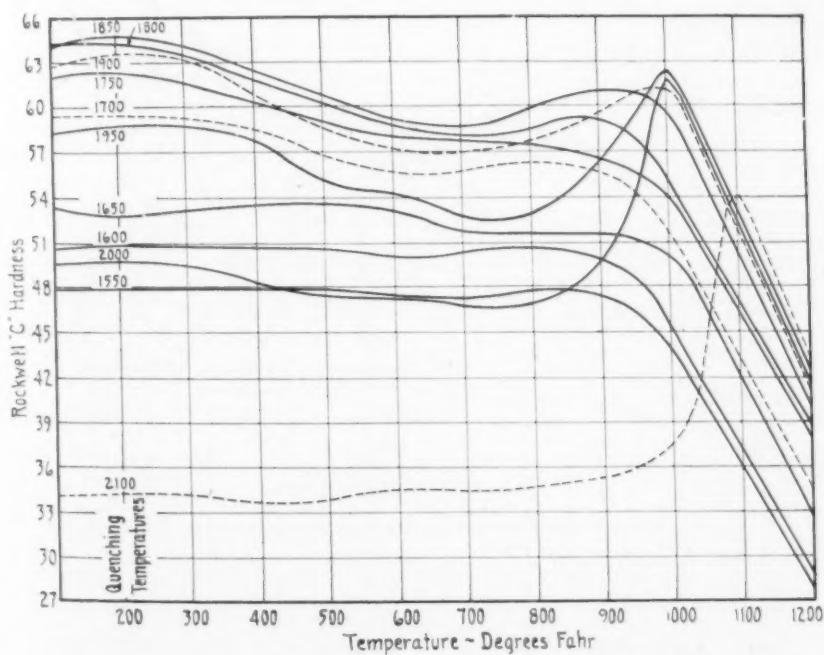


Fig. 34—Rockwell Hardness Vs. Tempering Temperature Curves for Steel C Quenched at Various Temperatures

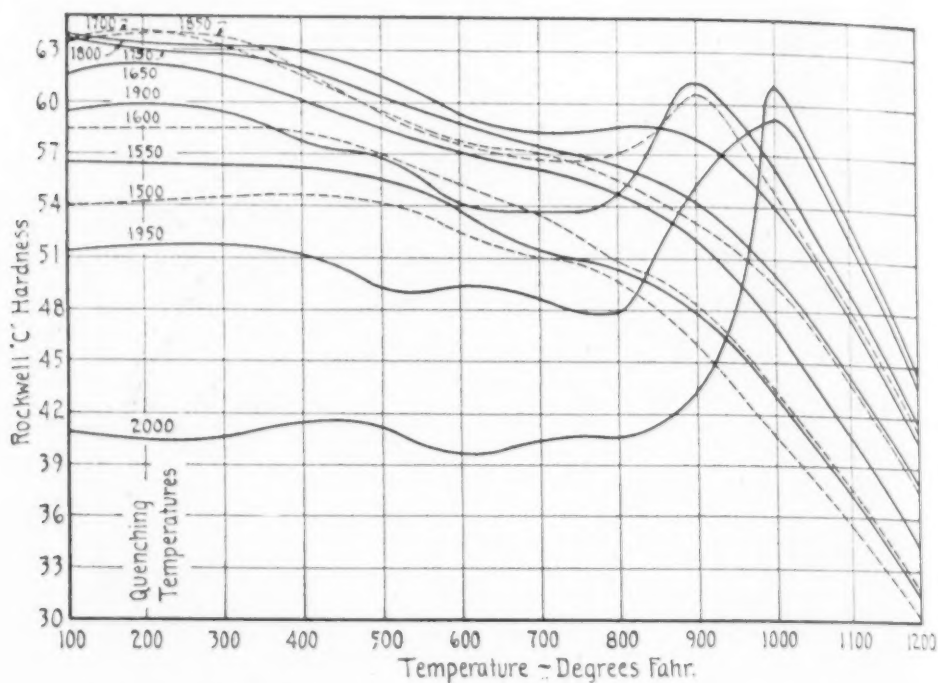


Fig. 35—Rockwell Hardness Vs. Tempering Temperature Curves for Steel D Quenched at Various Temperatures.

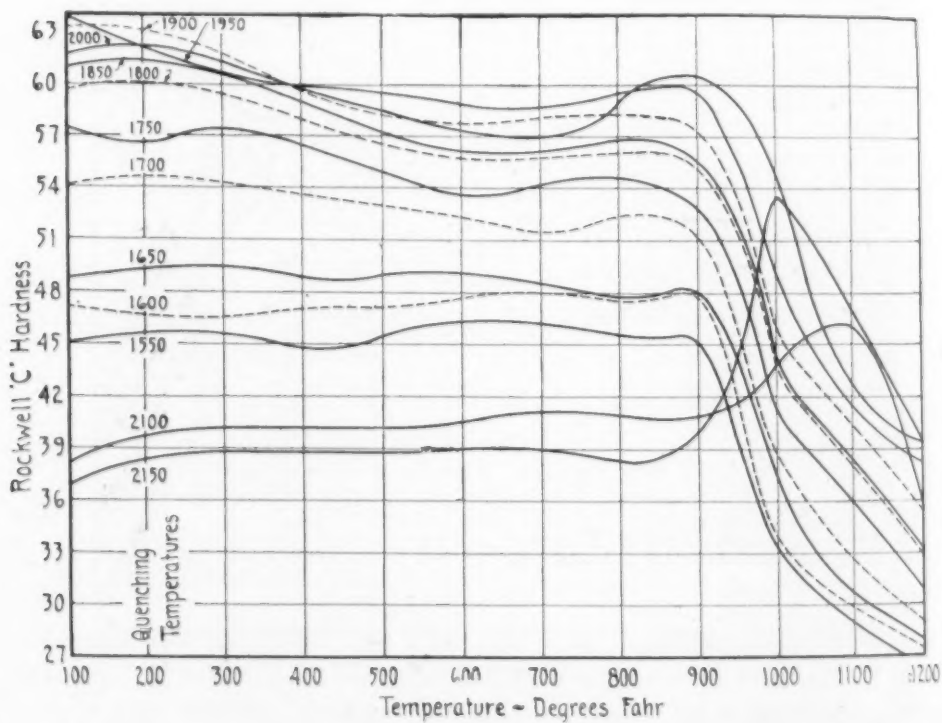


Fig. 36—Rockwell Hardness Vs. Tempering Temperature Curves for Steel E Quenched at Various Temperatures.

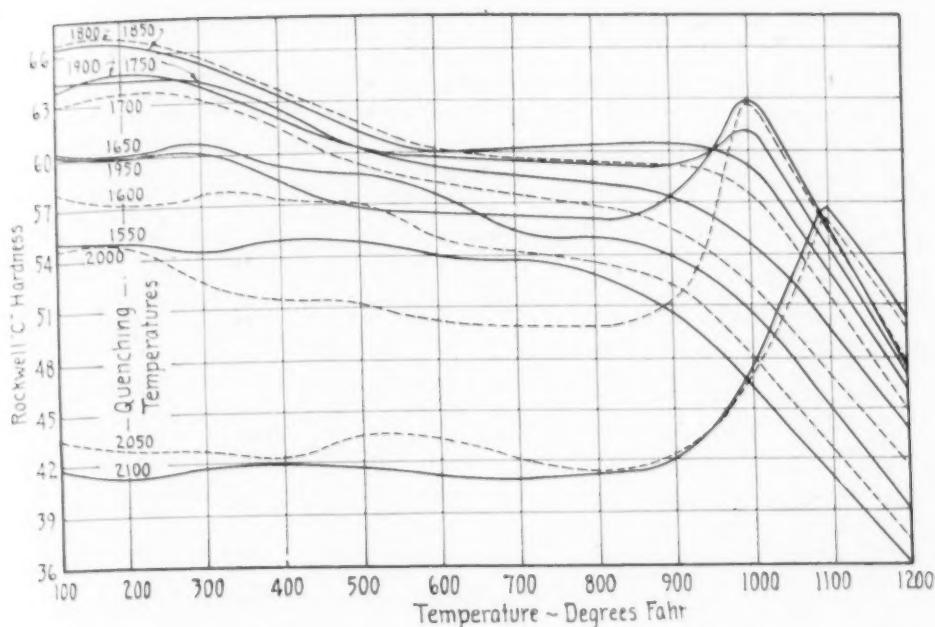


Fig. 37—Rockwell Hardness Vs. Tempering Temperature Curves for Steel H Quenched from Various Temperatures.

straight carbon-chromium steel and slightly highest in carbon. Of the four steels having the higher carbon content, the best distribution of the segregate is in steel "H," which contains both cobalt and vanadium.

CRITICAL POINTS

Murakami (2), Arnold and Read (3), Edwards, Sutton and Oishi (4) and many others have made an investigation of the thermal changes that take place on both the heating and cooling of chromium steels, yet the transformations of the high carbon, high chromium steels have only been briefly investigated. In order to compare the thermal changes of the six steels studied, heating and cooling curves were made of each of the steels. Three heating and three cooling curves were made of each steel, using a fully annealed specimen. (Figs. 39 and 40). Approximately 1 hour was required for heating the specimen from 800 degrees Fahr. to maximum temperature and 1 hour was also required to cool the specimen from maximum temperature to 700 degrees Fahr. One group of specimens was heated to 1750 degrees Fahr., after which they were immediately cooled with the furnace. The second group was heated to 1750 degrees Fahr., but held for 15 minutes at tem-

Table II
Hardness Results Obtained on Steels Investigated

Steel No.	How Treated	Deg. F.	Brinell Hardness Location Nos.										Rockwell Hardness C Scale Location Nos.	
			1	2	3	4	5	6	7	8	9	10	1	2
A	Air Cooled	1725	387	375	370	364	364	364	387	364	364	364	39	37
	Air Cooled	1825	430	424	418	402	402	402	418	418	402	402	43	43
	Oil Quenched	1725	683	683				683	683			683	65	65
B	Air Cooled	1825	444	387	375	364	361	351	402	387	364	361	44	42
	Air Cooled	1950	477	444	444	418	418	418	444	444	418	418	48	46
	Oil Quenched	1825	713					683	713				65	65
C	Air Cooled	1825	652	652				652	652			652	61	61
	Air Cooled	1925	652	652				652	652			652	62	62
	Oil Quenched	1825	683	683				683	683			683	63	63
D	Air Cooled	1800	477	444	418	387	387	387	444	402	387	387	46	44
	Air Cooled	1875	460	418	402	387	387	387	418	402	387	387	45	42
	Oil Quenched	1800	713	713				683	713				66	66
E	Air Cooled	1925	627	627				627	627			627	60	60
	Air Cooled	2000	627	627				627	627			627	58	57
	Oil Quenched	1925	683					683	683			683	63	63
H	Air Cooled	1800	424	418	387	387	375	364	402	387	387	364	45	42
	Air Cooled	1950	477	444	444			418	444		430	418	49	47
	Oil Quenched	1800	713	713				713	713			713	66	66

perature before cooling and the third group was heated to 1850 degrees Fahr., at which temperature the specimens were held for 10 minutes and then cooled.

Steel "A" shows two transformation points on heating, one

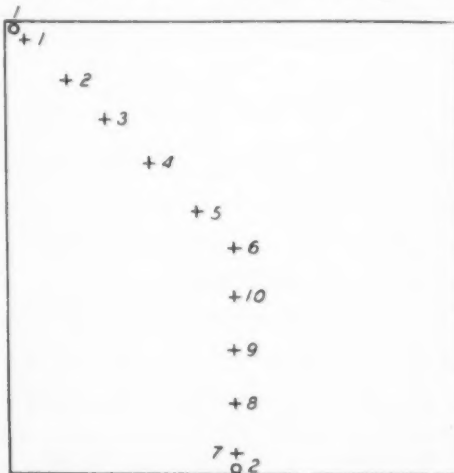


Fig. 38—Sketch Showing Relative Position of Rockwell and Brinell Tests on Face of 4-Inch Cube. Circle Indicates Rockwell C Impression, Cross Indicates Brinell Impression.

beginning at 1390 degrees Fahr. and the other at some 1450 degrees Fahr. On cooling only one point developed which began at some 1310 degrees Fahr. Cooling the steel from the higher tem-

perature, or holding at temperature a greater length of time did not change the position or increase the number of critical points on cooling. The intensity of the one point, however, was greatest when the steel was cooled immediately from 1750 degrees Fahr. and the intensity least when the steel was cooled from 1850 degrees Fahr.

Steel "B" showed two transformations on heating, beginning at 1380 degrees Fahr. and 1480 degrees Fahr. and on cooling one transformation beginning at 1310 degrees Fahr. The transformation on cooling was more prolonged than that of Steel "A" and was at maximum intensity when cooled from 1750 degrees Fahr. after holding for 15 minutes.

Steel "D" showed two transformations on heating, one beginning at 1380 degrees Fahr. and the other at 1480 degrees Fahr. On cooling, one transformation at 1310 degrees Fahr., the maximum intensity of which was shown when cooled immediately from 1750 degrees Fahr.

Steel "H" showed two transformations on heating, one beginning at 1370 degrees Fahr. and the other at 1390 degrees Fahr. The lower transformation was more prolonged than in any of the other steels. One transformation was found on cooling at 1350 degrees Fahr., most intense when cooled from 1850 degrees Fahr.

Steel "C" showed two transformations on heating, beginning at 1450 degrees Fahr. and 1530 degrees Fahr., the higher transformation of marked intensity compared with the lower. On cooling, one transformation was found at 760 degrees Fahr. quite intense when cooled from 1750 degrees Fahr. but nearly suppressed when cooled from 1850 degrees Fahr.

Steel "E" showed two transformations on heating, beginning at 1400 degrees Fahr. and 1510 degrees Fahr. and like Steel "C" the upper transformation was of unusual intensity as compared to the lower. On cooling two transformations developed, one beginning at about 1300 degrees Fahr. and the other at 700 to 770 degrees Fahr.; the upper transformation almost suppressed when cooling immediately from 1750 degrees Fahr. and the lower almost suppressed when cooling from 1850 degrees Fahr.

Most likely by varying the temperature from which cooling begins and the cooling rate, any of the steels studied could be made to develop two transformations on cooling; one in the neighbor-

hood of 1300 degrees Fahr. and the other in the neighborhood of 750 degrees Fahr. A comparison of the cooling curves determined under like conditions would indicate that Steels "C" and "E" would respond to air hardening to a greater degree than the other steels which is true.

The thermal changes of the high carbon, high chromium steels are similar to the thermal changes of an 18.00 per cent tungsten high speed steel and an interpretation of what takes place at each

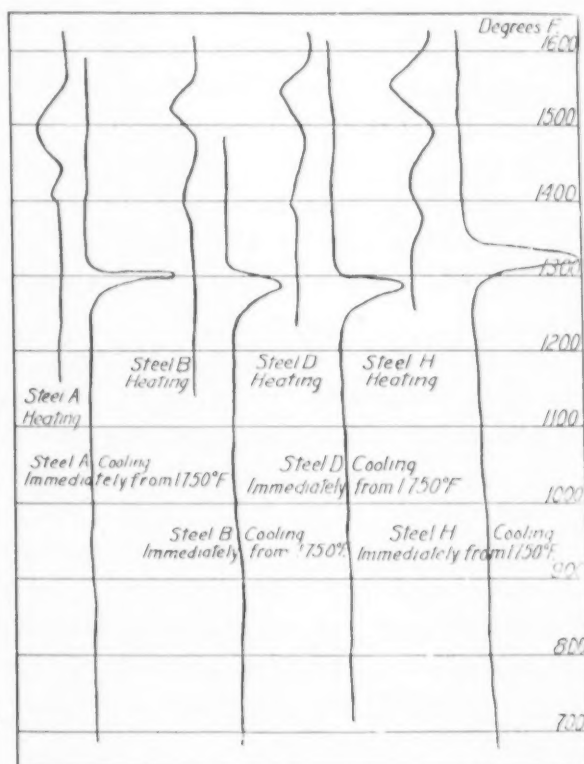


Fig. 39—Curves Showing Thermal Changes Occurring on Heating and Cooling Steels A, B, D and H.

transformation is equally as difficult. Apparently the first transformation on heating is the A_1 point and the second transformation the solution of the carbides, called by some investigators the carbide transformation. Since, some of the eutectic segregates may begin to dissolve at the carbide transformation and continue to dissolve with increase in temperature up to actual melting, its solution is not likely to be indicated with a definite point. An explanation of the changes on cooling is not so simple. If the upper point represented the carbide transformation, then steels showing

only one change at some 1300 degrees Fahr. would be expected to be quite hard by a suppression of the A_1 change which is not the case as will be found on referring to Table III which gives the hardness of each specimen after cooling. Is it possible then that when one change only takes place at some 1300 degrees Fahr. it

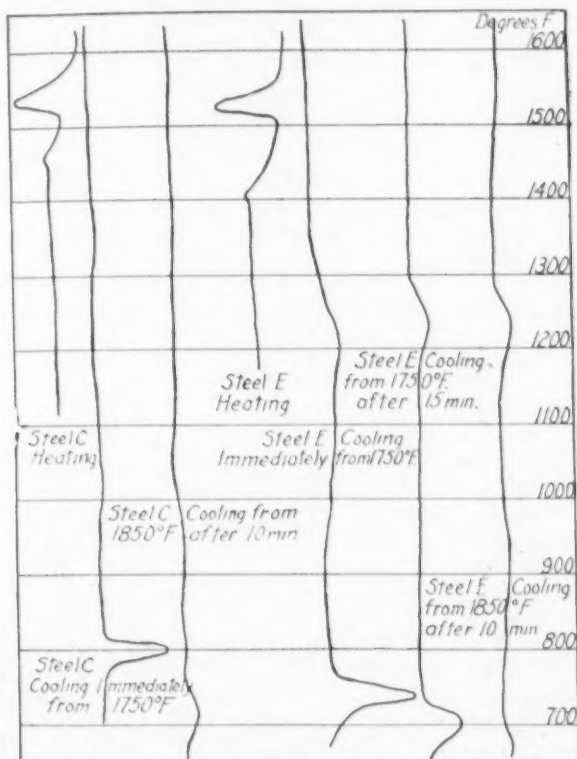


Fig. 40—Curves Showing Thermal Changes Occurring on Heating and Cooling Steels C and E.

is both the carbide and A_1 changes combined? Then, when only one change is apparent and at a low temperature, about 750 degrees Fahr., is it the A_1 transformation and the steel is partially hardened by suppressing the carbide change? It has been suggested by others that the upper point on cooling represents a change from austenite to troostite and the lower point from austenite to martensite. This would be in keeping with the hardness obtained after cooling but does not take into consideration a carbide change, and there is much evidence that there is such.

HARDENING AND TEMPERING CURVES

All of the steels used in plotting the hardening and tempering

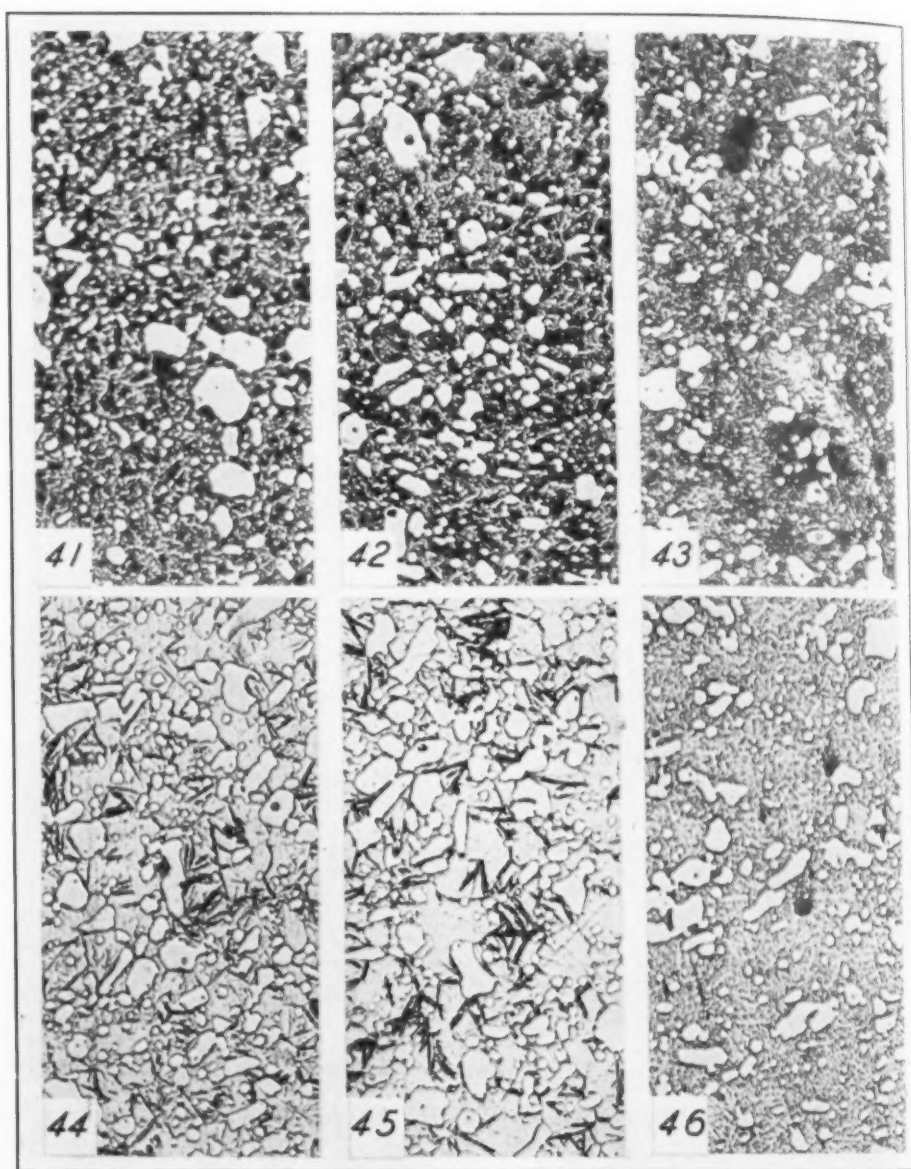


Fig. 41—Photomicrograph Showing Steel A. Hardened from 1750 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 42—Photomicrograph Showing Steel A. Hardened from 1750 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 43—Photomicrograph Showing Steel C. Hardened from 1750 Degrees Fahr. Tempered to 1100 Degrees Fahr. Fig. 44—Photomicrograph Showing Steel A. Hardened from 1900 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 45—Photomicrograph Showing Steel A. Hardened from 1900 Degrees Fahr. Tempered to 200 Degrees Fahr. Fig. 46—Photomicrograph Showing Steel A. Hardened from 1900 Degrees Fahr. Tempered to 1100 Degrees Fahr. All Photomicrographs $\times 500$.

curves were forged to $\frac{3}{4}$ -inch square bars and specimens were then cut $\frac{3}{4}$ -inch in length, making each specimen a $\frac{3}{4}$ -inch cube. The specimens were given a full anneal from 1625 degrees Fahr. and each specimen was used only once. All of the specimens were

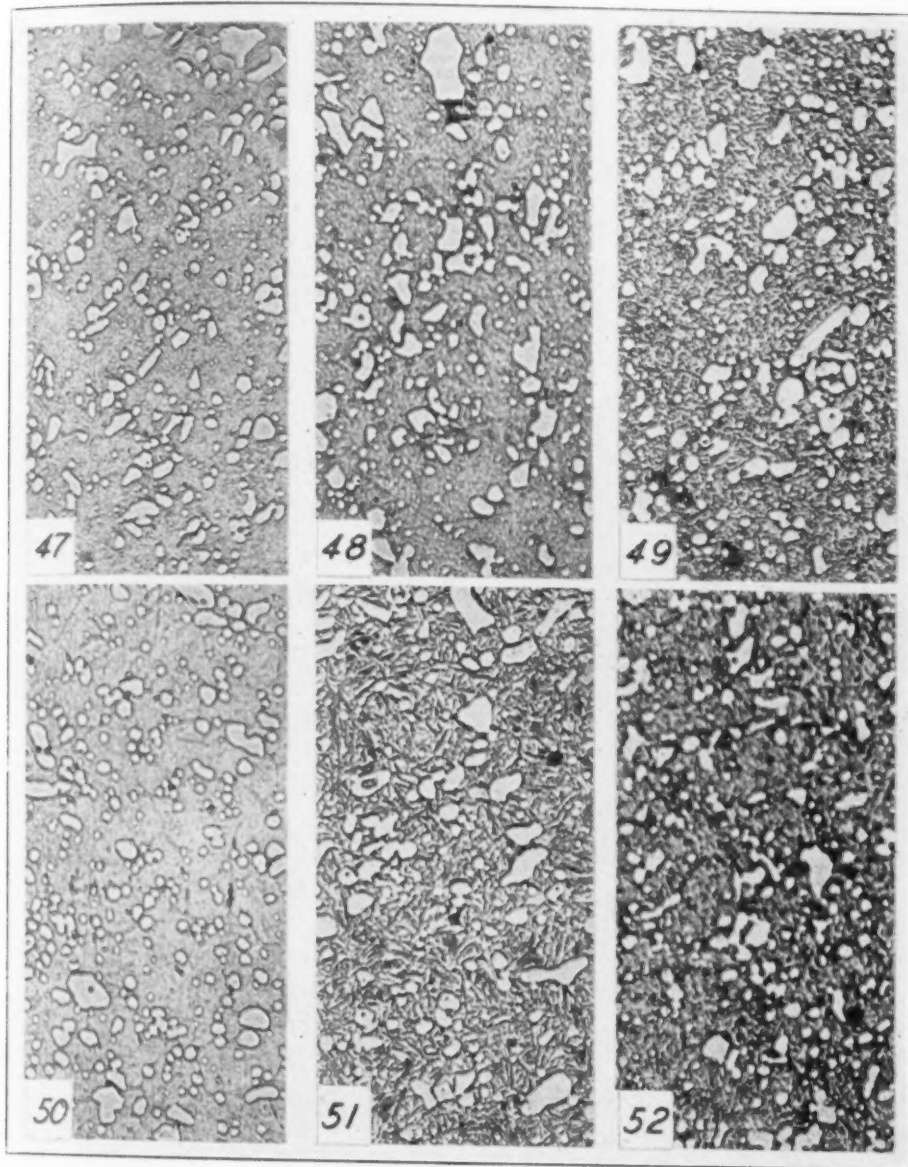


Fig. 47—Photomicrograph Showing Steel B. Quenched from 1750 Degrees Fahr. Tempered to 200 Degrees Fahr. Fig. 48—Photomicrograph Showing Steel B. Quenched from 1750 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 49—Photomicrograph Showing Steel B. Quenched from 1750 Degrees Fahr. Tempered to 1100 Degrees Fahr. Fig. 50—Photomicrograph Showing Steel B. Quenched from 1900 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 51—Photomicrograph Showing Steel B. Quenched from 1900 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 52—Photomicrograph Showing Steel B. Quenched from 1900 Degrees Fahr. Tempered to 1100 Degrees Fahr. All Photomicrographs $\times 500$.

were then treated in the open furnace but care, however, was exercised to keep the atmosphere of the furnace as near reducing as possible. The specimens were placed upon a heavy wire screen and raised

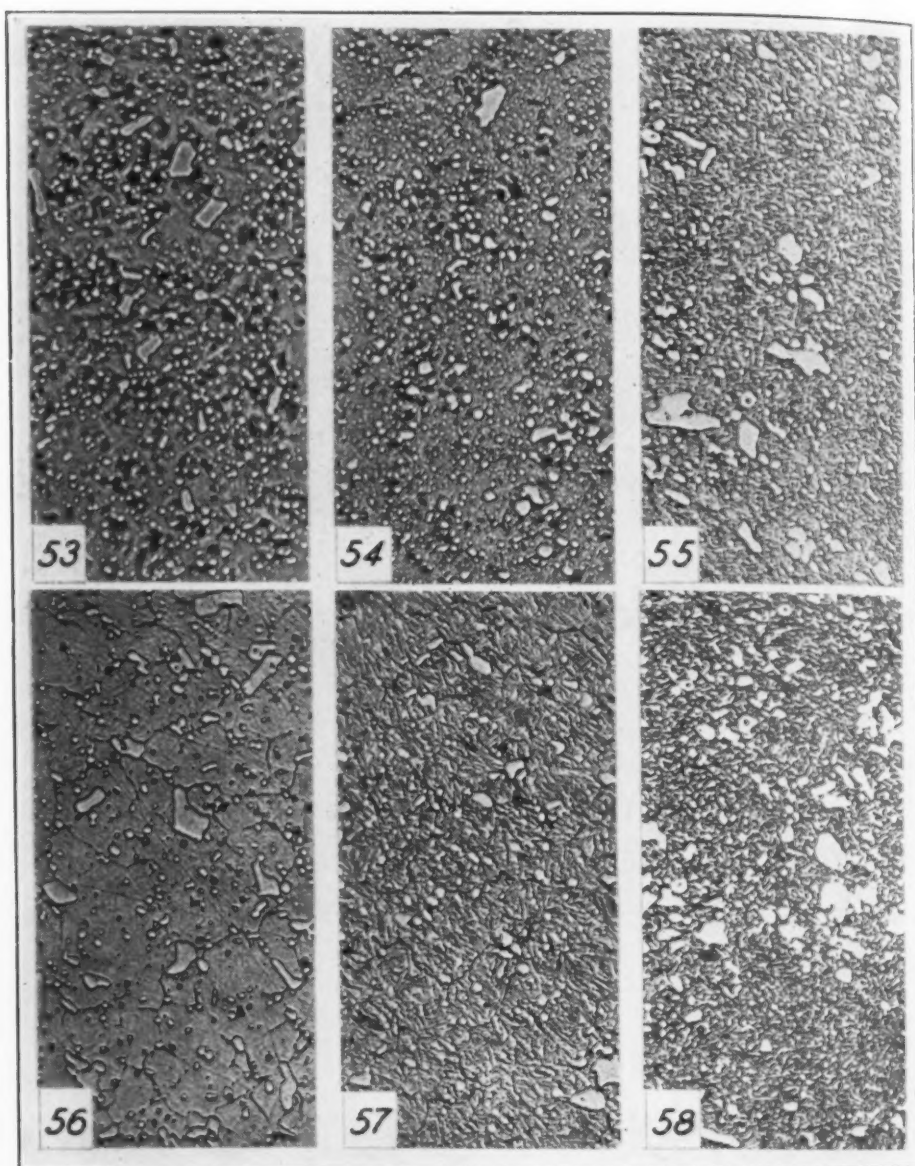


Fig. 53—Photomicrograph Showing Steel C. Hardened from 1750 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 54—Photomicrograph Showing Steel C. Hardened from 1750 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 55—Photomicrograph Showing Steel C. Hardened from 1750 Degrees Fahr. Tempered to 1100 Degrees Fahr. Fig. 56—Photomicrograph Showing Steel C. Hardened from 1900 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 57—Photomicrograph Showing Steel C. Hardened from 1900 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 58—Photomicrograph Showing Steel C. Hardened from 1900 Degrees Fahr. Tempered to 1100 Degrees Fahr. All Photomicrographs $\times 500$.

above the bottom of the furnace. All of the specimens were quenched in oil and were allowed to remain in the oil until they had practically reached the oil temperature. Twelve specimens were

treated at each quenching temperature in order to temper each specimen only once.

Each group of specimens was brought to temperature at a rate as nearly uniform as possible, varying from 20 to 30 minutes and all steels were held at temperature for 15 minutes before quenching with the exception of steel "E," which was held 35 minutes at temperature in order to insure maximum hardness. The quenching temperatures varied by 50-degree intervals, ranging from 1500 to 2100 degrees Fahr. The tempering temperatures varied by 100-degree intervals from 300 to 1200 degrees Fahr. In tempering the specimens approximately 45 minutes were required to bring the specimens to the tempering temperature, after which they were held for $\frac{1}{2}$ hour at the tempering temperature. Specimens which were tempered below 600 degrees Fahr. were heated in oil and those tempered above 600 degrees Fahr. were heated in salt or lead. After tempering, all of the specimens were air-cooled.

In making hardness tests the specimens were surface-ground to remove any decarburized surface. They were also ground slowly so that the heat developed in grinding would not affect the hardness. The hardness of each specimen represents the average of five Rockwell readings.

Because of the sluggishness in hardening of steels of this type each of the specimens was held at a specified quenching temperature different lengths of time in order to develop the time length to obtain approximate maximum hardness. This experiment showed that some types of the steels would develop maximum hardness at a specified temperature sooner than others. Upon determination of length of time necessary to hold at a specified temperature to obtain maximum hardness, hardness curves Fig. 31 were determined to obtain the quenching temperature which would produce maximum hardness. Upon referring to curves (Fig. 31) it will be noted that there is a wide difference between the temperatures which gave the maximum hardness for the six different steels.

Upon determination of the temperature which produced maximum hardness the tempering curves were determined from specimens quenched from a number of different temperatures as shown. The tempering curves are shown in Figs. 32 to 37. A study of the tempering curves reveals much interesting information about each of the different steels, particularly the rate of softening on temper-



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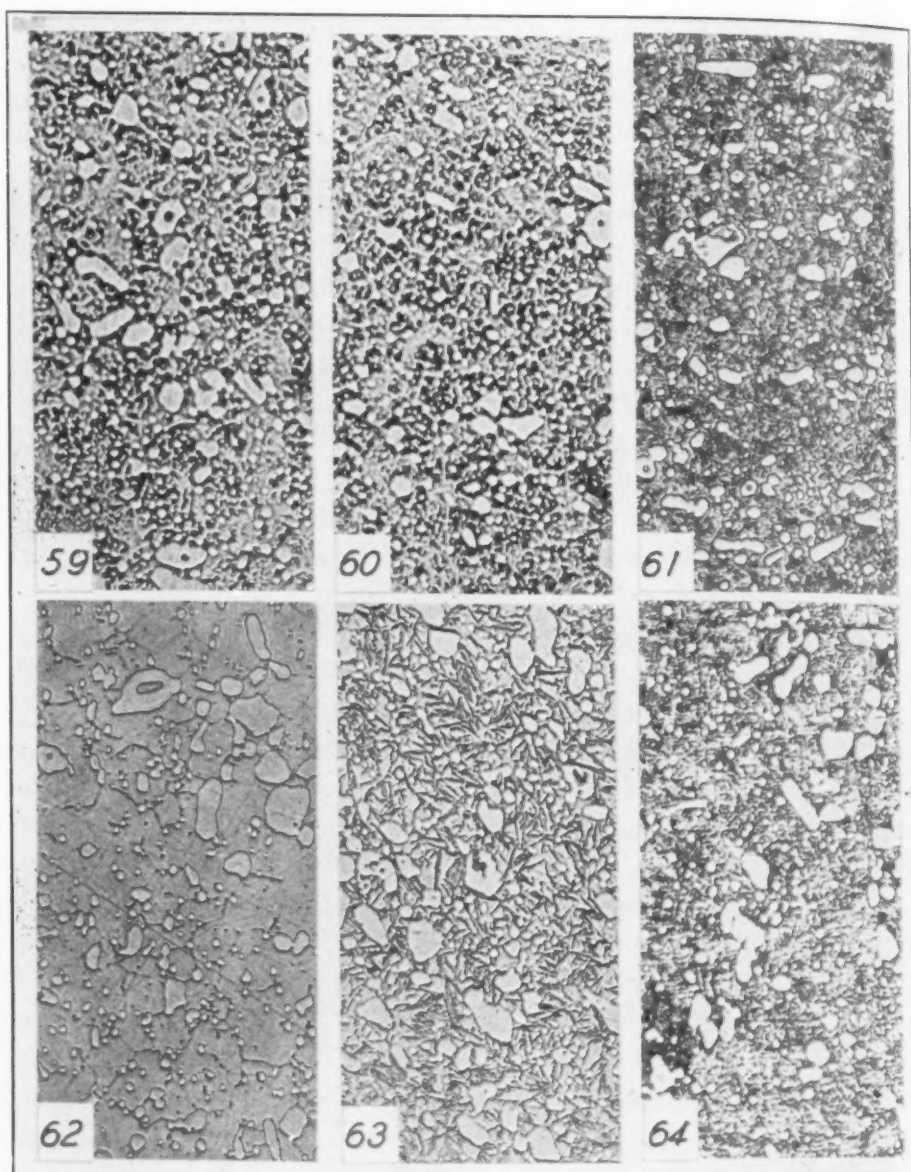


Fig. 59—Photomicrograph Showing Steel D. Quenched from 1750 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 60—Photomicrograph Showing Steel D. Quenched from 1750 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 61—Photomicrograph Showing Steel D. Quenched from 1750 Degrees Fahr. Tempered to 1100 Degrees Fahr. Fig. 62—Photomicrograph Showing Steel D. Quenched from 1900 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 63—Photomicrograph Showing Steel D. Quenched from 1900 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 64—Photomicrograph Showing Steel D. Quenched from 1900 Degrees Fahr. Tempered to 1100 Degrees Fahr. All Photomicrographs $\times 500$.

ing when the specimens had been hardened from the lower temperature and the rate of increase in hardness on tempering and tempering temperature at which maximum hardness resulted when

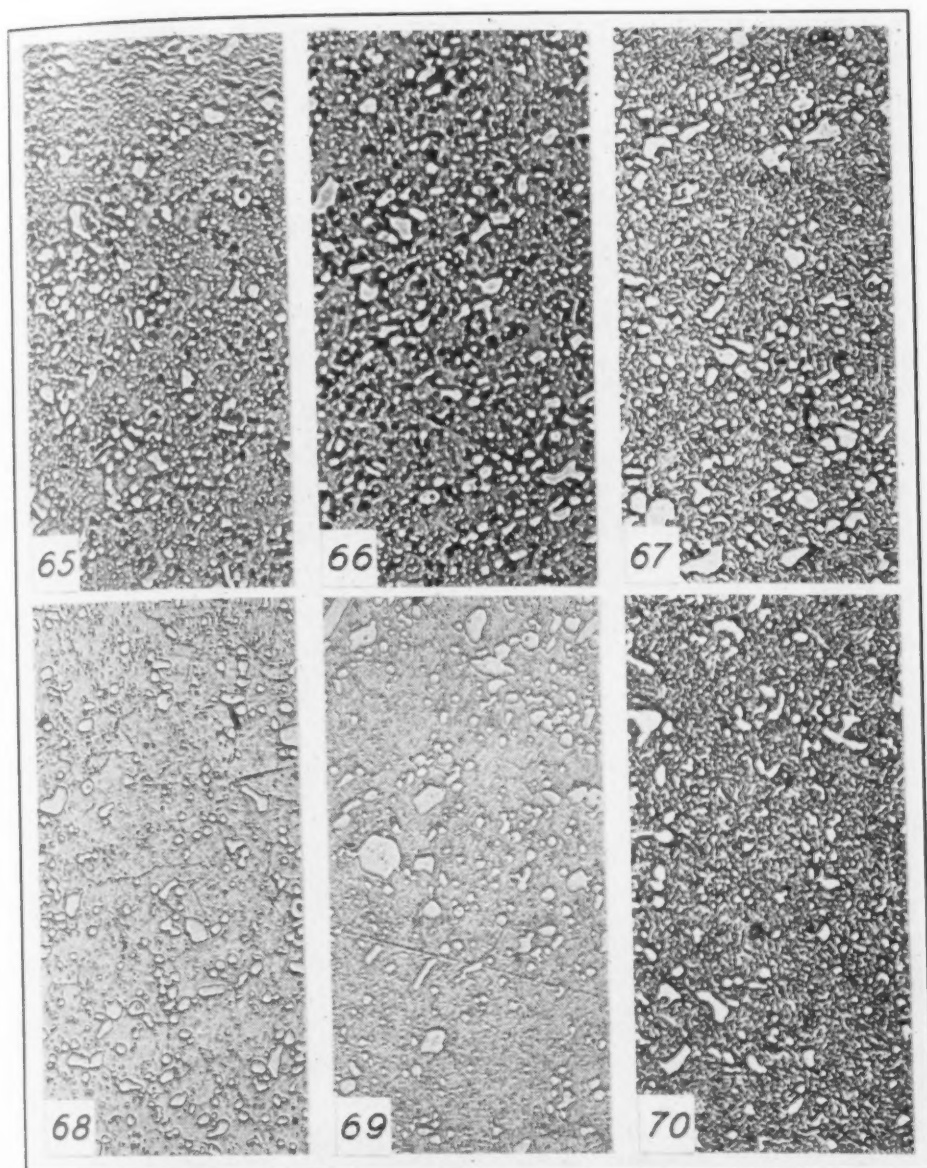


Fig. 65—Photomicrograph Showing Steel E. Hardened from 1750 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 66—Photomicrograph Showing Steel E. Hardened from 1750 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 67—Photomicrograph Showing Steel E. Hardened from 1750 Degrees Fahr. Tempered to 1100 Degrees Fahr. Fig. 68—Photomicrograph Showing Steel E. Hardened from 1900 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 69—Photomicrograph Showing Steel E. Hardened from 1900 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 70—Photomicrograph Showing Steel E. Hardened from 1900 Degrees Fahr. Tempered to 1100 Degrees Fahr. All Photomicrographs X 500.

the specimens had been quenched from the higher temperature. It will be noted in most instances that specimens which were hardened from the temperature which gave maximum hardness on

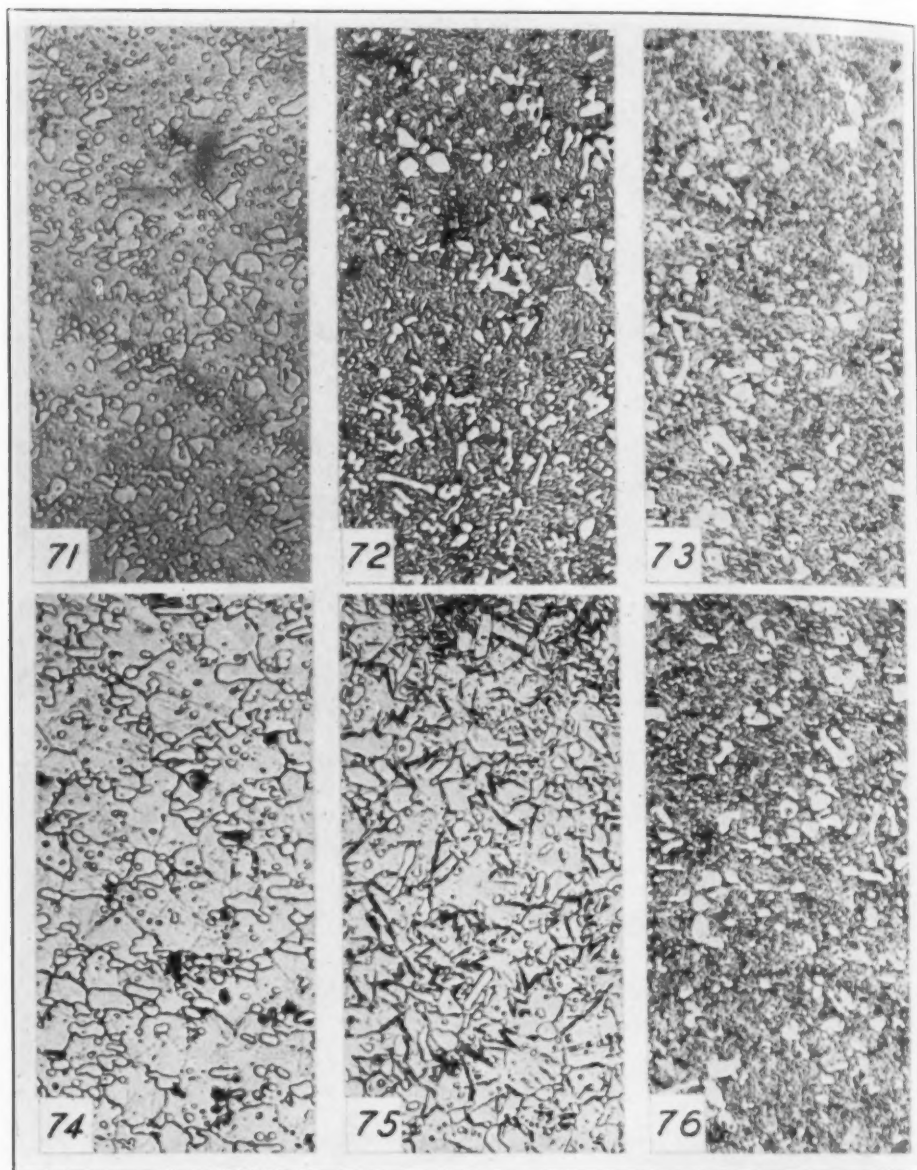


Fig. 71—Photomicrograph Showing Steel H. Hardened from 1850 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 72—Photomicrograph Showing Steel H. Hardened from 1850 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 73—Photomicrograph Showing Steel H. Hardened from 1850 Degrees Fahr. Tempered to 1100 Degrees Fahr. Fig. 74—Photomicrograph Showing Steel H. Hardened from 2000 Degrees Fahr. Tempered to 300 Degrees Fahr. Fig. 75—Photomicrograph Showing Steel H. Hardened from 2000 Degrees Fahr. Tempered to 700 Degrees Fahr. Fig. 76—Photomicrograph Showing Steel H. Hardened from 2000 Degrees Fahr. Tempered to 1100 Degrees Fahr. All Photomicrographs $\times 500$.

quenching also resisted the tempering action to the greatest degree without actually showing secondary hardness.

Much interesting information was obtained in making the

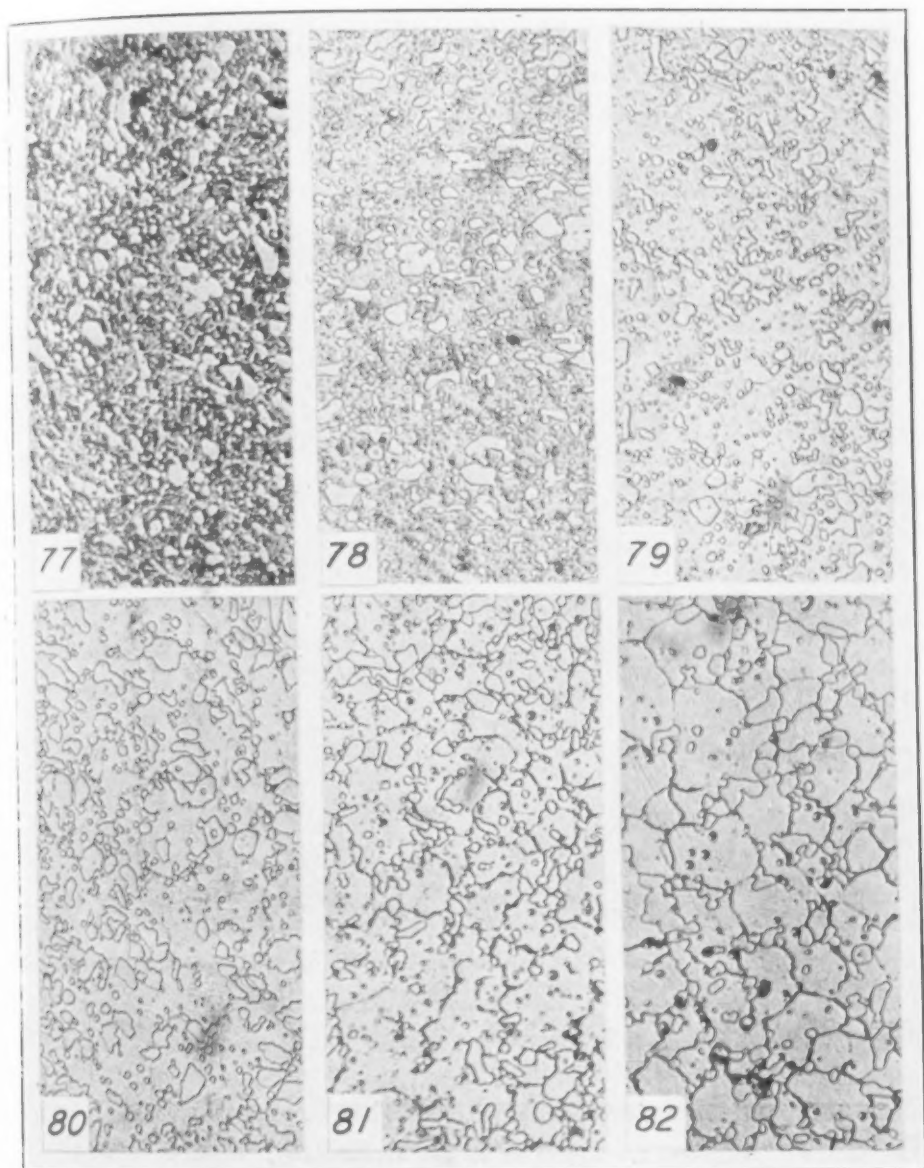


Fig. 77—Photomicrograph Showing Steel H. Hardened from 1600 Degrees Fahr. Not Tempered. Fig. 78—Photomicrograph Showing Steel H. Hardened from 1700 Degrees Fahr. Not Tempered. Fig. 79—Photomicrograph Showing Steel H. Hardened from 1800 Degrees Fahr. Not Tempered. Fig. 80—Photomicrograph Showing Steel H. Hardened from 1900 Degrees Fahr. Not Tempered. Fig. 81—Photomicrograph Showing Steel H. Hardened from 2000 Degrees Fahr. Not Tempered. Fig. 82—Photomicrograph Showing Steel H. Hardened from 2100 Degrees Fahr. Not Tempered. All Photomicrographs $\times 500$.

hardness curves. For instance, all of the steels were hardened within a space of several weeks and the determination of the tempering curves began with steels "B" and "H." At least three

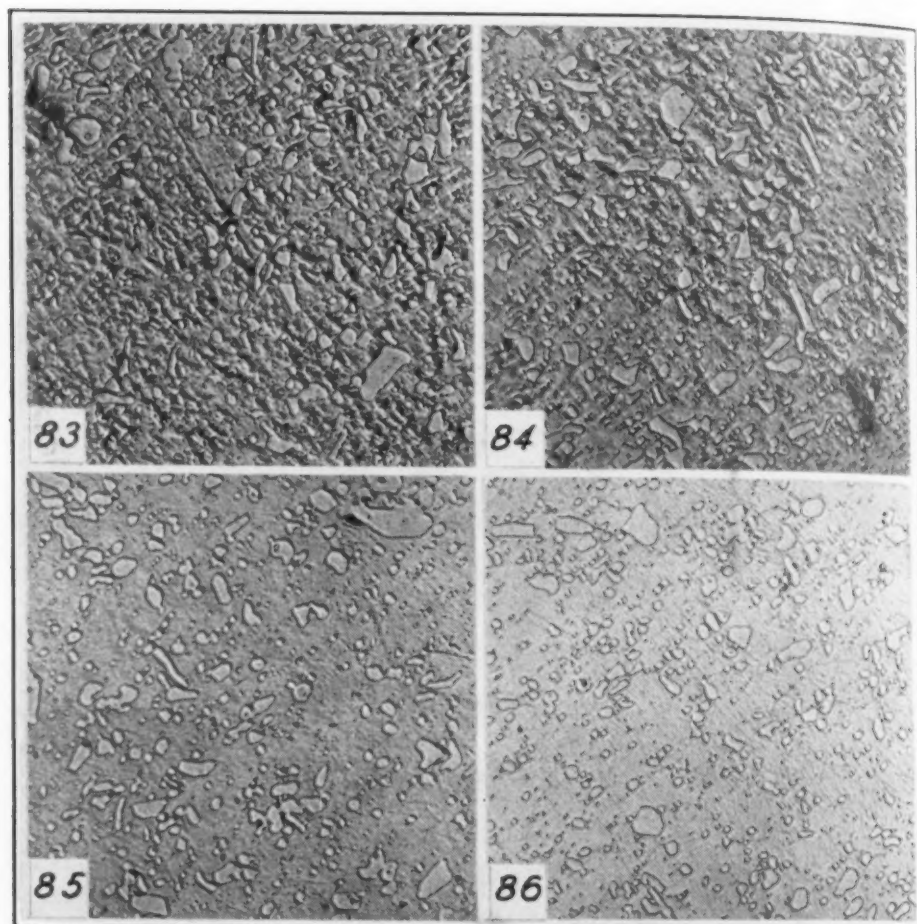


Fig. 83—Photomicrograph Showing Steel E. Held at 1800 Degrees Fahr., 5 Minutes. Not Tempered. Fig. 84—Photomicrograph Showing Steel E. Held at 1800 Degrees Fahr., 15 Minutes. Not Tempered. Fig. 85—Photomicrograph Showing Steel E. Held at 1800 Degrees Fahr., 30 Minutes. Not Tempered. Fig. 86—Photomicrograph Showing Steel E. Held at 1800 Degrees Fahr., 45 Minutes. Not Tempered. All Photomicrographs $\times 500$.

months elapsed after hardening the specimens from steels "C" and "D" before they were tempered to the different temperatures. Upon testing the specimens from the two latter steels it was found that the hardness had dropped from one to two divisions on the Rockwell scale, apparently because of the aging effect. This was more particularly noticeable in the specimens which had a Rockwell hardness exceeding 63 C. In determining the tempering curves no allowance was made for this effect. All of the steels scaled heavily at high temperatures; that is, from 1950 to 2100 degrees Fahr. but even at this temperature, steel "C" resisted the scaling action to a greater extent than any of the other steels. At lower temperatures

Table III
Hardness of Steels after Cooling from Determination of Thermal Changes

Steel	Cooled from Degrees Fahr.	At temp. minutes	Rockwell Hardness C
A	1750	0	33
	1750	15	36
	1850	10	38
B	1750	0	30
	1750	15	33
	1850	10	38
C	1750	0	49
	1750	15	51
	1850	10	55
D	1750	0	30
	1750	15	32
	1850	10	36
E	1750	0	46
	1750	15	46
	1850	10	47
H	1750	0	28
	1750	15	32
	1850	10	35

all of the steels scaled very little, while steel "C" practically did not scale. Steels "C" and "E," which steels had the lowest carbon contents of the six were sluggish and required the greatest time at temperature to obtain maximum hardness; "E" requiring considerably more time than "C." Some of the steels reacted to the hardening temperatures much more uniformly than others as would be assumed when the steels hardened sluggishly. It is interesting to note that steels "B" and "H" hardened most uniformly of the six steels and both of these steels contained a high percentage of vanadium.

AIR HARDENING

Some of the steels react much differently than others when air-cooled as would be assumed from a study of the critical points. In order to determine the relative degree of hardness on air cooling, 4-inch cubes were forged from each of the different steels. Specimens were chosen sufficiently large so that the mass effect would have some relation to the hardness; therefore, showing a

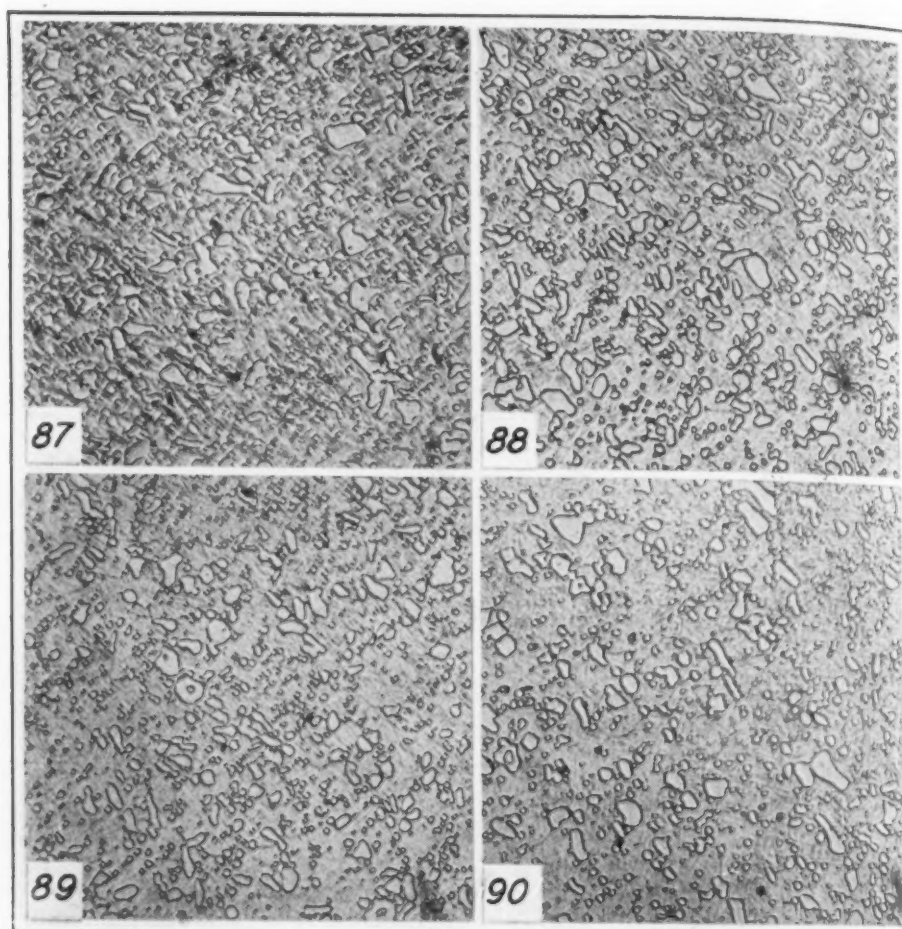


Fig. 87—Photomicrograph Showing Steel H. Held at 1800 Degrees Fahr. 5 Minutes. Not Tempered. Fig. 88—Photomicrograph Showing Steel H. Held at 1800 Degrees Fahr. 15 Minutes. Not Tempered. Fig. 89—Photomicrograph Showing Steel H. Held at 1800 Degrees Fahr. 30 Minutes. Not Tempered. Fig. 90—Photomicrograph Showing Steel H. Held at 1800 Degrees Fahr. 45 Minutes. Not Tempered. All Photomicrographs $\times 500$.

greater difference between the hardness of the different steels than if the specimens were so small that by cooling rapidly the difference in the comparative results would be less. Specimens were cooled in still air from two different temperatures; the temperatures being chosen which were thought to give approximate maximum hardness that could be obtained by air cooling. One specimen was also oil-quenched from a temperature previously determined to give maximum hardness on oil quenching.

All of the specimens were packed in charcoal to prevent decarburization and were then surface-ground on one face to a depth of about thirty thousandths before hardness readings were taken. The

hardness readings were made diagonally across the face as well as vertically. The Brinell tests were taken within $\frac{1}{4}$ -inch of the edges and the Rockwell tests were taken within $\frac{1}{8}$ -inch of the edges. Fig. 38 shows the relative position of both the Rockwell and Brinell tests and in Table II will be found the hardness results of the different steels corresponding to the numbers noted on the diagram.

MICROSTRUCTURE RESULTING FROM HARDENING AND TEMPERING

In order to compare the microstructures of the different steels resulting from hardening and tempering a number of the specimens used in determining the hardness curves were selected and photographed. These photomicrographs are shown in Figs. 41 to 76. Much detailed information concerning these steels can be obtained from a study of the photomicrographs. An explanation, however, of the photomicrographs would require considerable space and is hardly necessary in view of the fact that to any one particularly interested in this phase of the subject, the photomicrographs should be self-explanatory. All of the specimens were etched with an alcoholic solution containing 4 per cent nitric acid. The microstructure resulting from quenching from different temperatures is shown of only one steel, namely, "H," shown in photomicrographs Figs. 77 to 82. The effect of time on rate of solution of alloys in the different steels is shown in photomicrographs, Figs. 83 to 90.

PHYSICAL PROPERTIES

A few of the physical properties of the different types were determined, including the elastic limit, tensile strength, percentage of elongation, the percentage of reduction in area, the specific gravity after quenching from various temperatures and the movement and distortion resulting from hardening. Impact tests were made but due to our inability to obtain satisfactory checks the results are omitted.

The tensile tests do not offer as good a comparison as they would were the hardness of all of the specimens approximately the same. The two steels showing the lower carbon content show the highest percentage of elongation and reduction in area as would be expected; while the hardest steel, namely, type "D" shows the highest tensile but a low percentage of reduction in area and elon-

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Tensile Tests

Steel No.	Elastic Limit, lbs. per sq. inch	Tensile Strength, lbs. per sq. inch	Per Cent Elongation in 2 inches	Per Cent Red. in Area	Brinell Hardness
A	57,500	107,750	5.0	5.8	228
B	56,250	104,250	11.0	13.3	217
C	51,500	103,000	21.5	34.0	223
D	62,500	110,250	6.5	5.8	255
E	50,500	102,500	13.5	18.8	217
H	51,000	103,500	12.5	14.0	212

gation. Steels "B" and "H" both containing vanadium show the best combination of properties of the four steels having the higher carbon content.

Tests for movement and deformation resulting from hardening

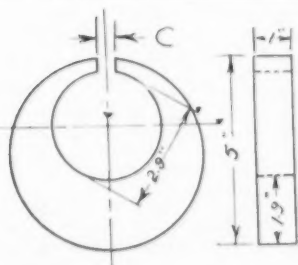


Table IV
Opening in Inches at C

Steel	Annealed	Hardened	Tempered at 300 Degrees Fahr.
A	0.5033	0.5280	0.5280
B	0.5020	0.5150	0.5140
C	0.5020	0.5056	0.5058
D	0.5020	0.5090	0.5086
E	0.5038	0.5080	0.5085
H	0.5010	0.5113	0.5120

were made with rings and with test pieces copied from those used for a similar purpose by the United States Navy. The results are shown in Tables IV and V. The steel was in each case hardened

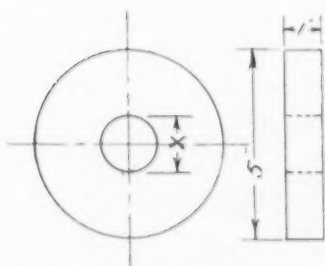


Table V
Change of Dimension Hole X on Hardening

Steel	Size of Hole in Inches		Tempered at 300 Degrees Fahr.
	Annealed	Hardened	
A	1.5492	1.5507	1.5503
B	1.5490	1.5492	1.5491
C	1.5490	1.5488	1.5491
D	1.5490	1.5472	1.5472
E	1.5501	1.5482	1.5480
H	1.5485	1.5469	1.5468

from that temperature which would produce maximum hardness. The test pieces were wholly hardened.

In Table VI are shown the specific gravities of steel "H" after quenching from different temperatures.

Table VI
Specific Gravity of Steel H on Quenching from Different Temperatures

Number of Specimen	Degrees Fahr. Quenched	Rockwell Hardness	Specific Gravity
H	Anneal		7.715
H-1	1550	55.1	7.690
H-2	1600	58.0	7.686
H-3	1650	60.3	7.680
H-4	1700	63.1	7.677
H-5	1750	64.4	7.683
H-6	1800	66.8	7.673
H-7	1850	66.5	7.688
H-8	1900	63.7	7.695
H-9	1950	60.2	7.721
H-10	2000	54.4	7.754
H-11	2050	43.5	7.763
H-12	2100	41.8	7.800

USES

Certain physical characteristics of high carbon, high chromium steels such as high resistance to wear, nondeformation on hardening and ability to harden in oil or air, adapt it to a wide variety of tools and dies. The possible applications of the steel are almost unlimited, but a few of the uses for which it is especially suited are as follows: blanking dies, drawing dies, coining dies, forming dies, thread rolling dies, trimming dies, shear blades, punches, lathe centers, gages, bushings, certain types of cold heading dies, rolls for cold forming, seaming rolls, wear plates, brick mold liners, cutting tools for brass and bronze, guides, mandrels, etc.

RESUME

Steels "C" and "E" are the only two steels of the group that will harden satisfactorily in medium and large sections when air-cooled. Likewise steels "C" and "E" apparently do not have nearly as good wearing qualities as the other four steels, due to the smaller carbide and eutectic content.

Steel "C" resisted oxidation at high temperatures much better than the others. All of the steels when hardened and polished resist staining to a fair degree.

Steel "E" required the greatest length of time at temperature to produce maximum hardness with steel "C" requiring the next greatest. Steel "H" hardened the most uniformly of the group with steel "B" next; both steels containing vanadium. Steels "H" and "B" could be annealed the softest; "H" slightly

softer than "B." Steels "H" and "B" could be hardened to the greatest degree of hardness using commercial hardening methods, while steels "C" and "E," both of the lower carbon content when hardened to maximum hardness, were the least hard of the group.

Steel "A" was most capable of secondary hardening after austenization; the secondary hardness being about 65.5 Rockwell C. All of the steels had excellent nondeforming characteristics.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the assistance rendered in the preparation of the data contained in this paper by Messrs. R. B. George, H. G. Johnstin and R. S. Rose of the metallurgical laboratory of the Vanadium-Alloys Steel Company.

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DISCUSSION

Written Discussion: By M. A. Grossmann, Central Alloy Steel Corp., Canton, O.

J. P. Gill has rendered a great service in reporting on the properties

1929

of the high carbon high chromium steels. The data reported here represent a very large amount of painstaking work.

One of the aspects of the work is the relation of the critical point curves to the hardness obtained after heat treatment. As stated by Mr. Gill on page 404, the thermal changes are similar to those in an

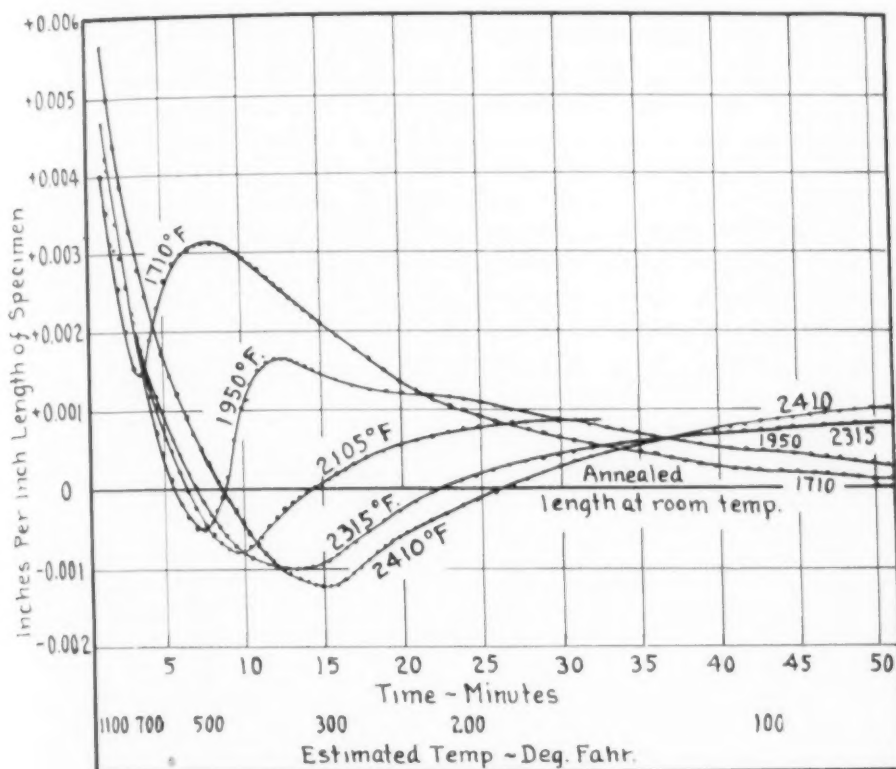


Fig. A—Time-Shrinkage Curves of High Speed Steel Showing Change of Length During the Hardening While High Speed Steel is Being Cooled from the Hardening Temperature. The Hardening Temperature is Indicated on Each Curve. Readings Cover the Interval of Cooling from 1100 Degrees Fahr., to Room Temperature.

18 per cent tungsten high speed steel. This is quite true and will serve as an excuse for quoting here some similar observations made on high speed steel. As stated quite properly by Mr. Gill on page 405, the upper critical point on cooling, namely the one at about 1300 degrees Fahr, is taken to represent the change from austenite to troostite. The lower critical point on cooling, namely the one in the neighborhood of 700 degrees Fahr., represents the change from austenite to martensite. The latter transformations, since they produce martensite, lead to greater hardness than those which form troostite. Thus the steels which show the troostite transformation on page 404 are reported on page 415 as giving the lower Rockwell hardness from 28 to 38, and those which show the martensite transformation on page 405 give the higher Rockwell hardnesses 46 to 55. It will be observed on page 405 that the steels cooled

immediately from 1750 degrees Fahr. show a sharp martensite transformation. Those heated for a longer time at this temperature or those heated to a higher temperature preparatory to cooling, show a martensite transformation which is much less pronounced.

The accompanying Fig. A gives some indication as to why the critical points are less pronounced when the steel has been heated to a higher temperature before cooling. The curves are time shrinkage curves taken on high speed steel during cooling from the hardening temperature. It will be observed that at the lowest quenching temperature a certain amount of martensite is formed and the transformation is completed quickly. As the quenching temperature is raised the transformation is less sharp and takes place over a wider range of temperature. The total amount of martensite formed is also larger when the quenching temperature is higher. This would explain two facts brought out in Mr. Gill's paper: first, that as the quenching temperature is raised the martensite transformation is more difficult to distinguish, and second, that the steel is harder after a quench at 1850 than after a quench at 1750.

Written Discussion: By A. H. Kingsbury, Crucible Steel Co., of America.

Mr. Gill is to be congratulated on the intelligent and thorough manner in which he has pursued the investigation, the completeness of which has resulted in some very valuable data both from a technical and a practical viewpoint.

Much of my experience with this type of steel has necessitated investigations along some of the lines pursued by the author and, generally speaking, the results of these investigations correspond very closely with those obtained by him.

In Fig. 36, representing a Rockwell hardness vs. tempering temperature curve for steel E, the curve for 2100 appears to be inconsistent in relationship to the 2150 curve. It will be noted in the case of the 2150 curve that secondary hardening commences at a temperature of about 850 degrees Fahr. and reaches its maximum at 1000 degrees Fahr., the maximum hardness obtained on secondary hardening being about C 53. In the case of the 2100 curve, secondary hardening is indicated as commencing at about 100 degrees higher or at 950 degrees Fahr. and reaches a maximum at 1100 degrees Fahr. In comparison with the 2150 hardening, the secondary hardening effect at 2100 is slight, reaching a maximum of but about C 46.

Assuming that 2100 to 2150 for this steel represents the temperature of maximum austenization, it is difficult to understand why the lower hardening temperature should show such an apparent contradiction to the curves for the other steels representing the same condition.

In the resume, the author states that steels B and H could be annealed the softest. Is this predicated upon the results shown in Table III? If so, it will be noted that steel D, which is a non-vanadium steel, compares very favorably with B and H. Further, this steel, with the exception of its higher chromium content, is similar in analysis to A.

The statement is also made that H and B attain the greatest degree of hardness. Judging by the curves, it appears that the difference between them and A is indeed very slight. In this connection, my own investigations have indicated that the addition of vanadium to a straight carbon-chromium base does not appreciably increase the maximum degree of hardness obtainable.

Written Discussion: By W. H. Wills, Atlas Steel Corp, Dunkirk, N. Y.

This paper brings out many interesting points about the nature of a type of steel that can really be termed one of the later developments of the tool steel industry. The number and variety of its applications are constantly growing so that today practically all of the tool steel manufacturers have a regular grade of this type.

The writer's experience has been confined to experiments with a type similar to steel A, and in this connection a few points may be of interest.

(1) *Forging.* The steel is handled much like high speed steel, but requires more time in heating and is worked at a lower temperature. Also the temperature limits between which it works best are narrower than for high speed steel.

(2) *Heat Treatment.* In general, pack hardening has given best results in service as this insures slow heating and the surface of the parts are protected during the long time necessary at temperature to obtain proper solution of the carbides. This latter condition is essential for maximum hardness and wearing quality. However, some users prefer the open fire treatment and we have heard of hardening temperatures all the way from 1400 up to 1750 degrees Fahr. Prolonged heating in the open fire will result in decarburization which if not fully removed results in inferior wearing quality. From this standpoint it would appear that a carbon content well up in the range represented by these steels is desirable.

The steel when properly pack hardened will develop full hardness on the surface showing uniformly 65 to 67 Rockwell C, and this hardness has been obtained with sections as large as the equivalent of a 3-inch cube.

It is possible to carburize the steel and a case 50 points higher than the normal carbon content was produced by packing in Stecho and running three hours at 1800 degrees Fahr. This piece when afterwards hardened along with an untreated sample developed about 1 point higher Rockwell hardness.

(3) *Dimensional Changes in Hardening.* After standard treatment at 1700 degrees Fahr. with a temper at 400 degrees Fahr., 1-inch round test pieces show an expansion of 0.0005-inch per inch. This temper, which is common for die work, showed the least change from original size of the tempering temperatures in practical use. Checking three dimensions on a rectangular test block, the length showed the least change per inch and the thickness the most. Shrinkage took place on length only at an 850 degree Fahr. temper.

(4) *Resistance to Impact.* The impact value of the steel is low with any regular heat treatment. When austenitized and tempered back

to full secondary hardness higher impact values are obtained. While low impact value limits the steel's applications to some extent, nevertheless by designing tools to allow extra size of section it has been possible to eliminate failures by breakage and improve average runs.

(5) *Machinability.* Besides low impact value, machinability sometimes presents a problem with this steel. In the fully annealed condition, the Brinell hardness should run 228 to 248 or about the same as high speed steel. In spite of this, some users find it considerably more difficult to machine than high speed. However, where large production runs are looked for, which happens very often, the user is in general perfectly willing to stand the extra machining cost.

Written Discussion: By H. G. Keshian, metallurgist, Chase Companies, Inc., Waterbury, Conn.

The development of high carbon and high chromium steels is one of the outstanding achievements of the tool steel manufacturers in recent years. Indeed in many ways this steel is remarkable, essentially it is a superior type of oil hardening steel, capable of greater hardness, of excellent wearing property and non-deforming characteristics. In my experience I have observed that this steel in annealed condition, with a Brinell hardness of about 250, has as great wearing properties in drawing wire as hardened 1 per cent carbon tool steel with a Brinell hardness of 650. In the hardened condition with a Brinell hardness of 600, it has a wearing property 7 times as great as the 1 per cent hardened carbon steel and twice that of hardened 4 per cent tungsten and 1.40 per cent carbon finishing steel and 10 times as great cutting properties as the regular oil hardening carbon manganese steel.

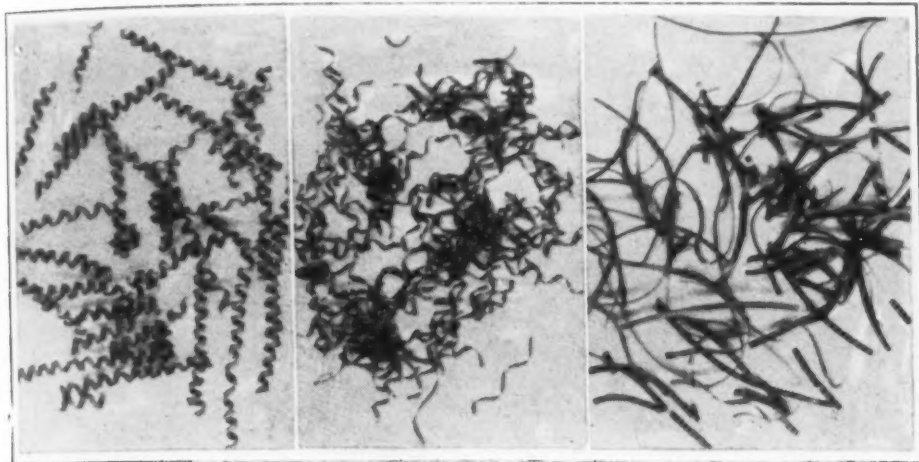
Yet there is a good deal to be learned about this steel, and Mr. Gill's paper is a most welcome contribution to our knowledge on the subject and will be much appreciated by those users who have recognized the many possibilities of this material. Mr. Gill has, as in his previous papers, made this one doubly valuable by including in his study such types as are quite similar to those now used in this country.

Having had some experience with high carbon high chromium steel, for metal working tools, I wish to take this opportunity, therefore, to say a few words on a phase of the subject which Mr. Gill has, perhaps, overlooked, namely, the difficult machining characteristics of this type of steel. It has been my experience that this type of steel is much more difficult to machine or file than the regular high speed steel. Where the tools require fine milling or hand tooling operations the difficulty becomes more serious and resorting to slower speeds does not afford a satisfactory solution. The grinding of this type of steel presents similar difficulty as for machining or finishing.

Unquestionably the presence of high carbon together with high chromium is responsible for this difficult machining and as we do not have any serious trouble with carbon steels containing from 2 to 2.25 carbon generally used for machining hard metals such as chilled rolls and some sand castings and for similar purposes, it can hardly be the carbide

of iron that causes the difficulty. Possibly it is the carbide of chromium and the manner in which it occurs in the steel that makes the steel so difficult to machine.

Addition of 1 per cent nickel, or vanadium, or lowering the carbon from 2 to 1.5 per cent like the steels "C" and "E" in Mr. Gill's Table I,



Steel No. 1—Brinell-255

Steel No. 1—Brinell-340

Steel No. 2—Brinell-207

Fig. 1—Photograph of Chips Obtained by Turning 3-Inch Diameter Samples on a Lathe with a Peripheral Speed of 47 Feet per Minute. Note that Steel No. 2 Machines Harder than Steel No. 1 with Brinell Hardness of 255 or 340.

Steel	Carbon	Chromium	Vanadium	Molybdenum
No. 1	2.20	12	0.25	
No. 2	1.48	12	1.00	1.00

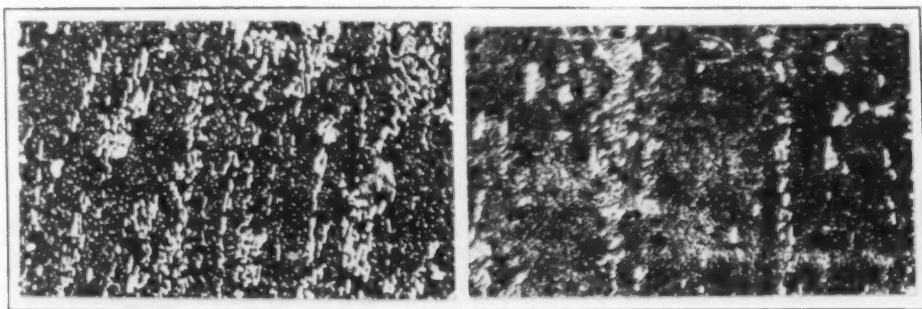


Fig. 2—Photomicrographs of Steels Nos. 1 and 2, Respectively.

does not seem to help matters much. In the annealed condition steels similar to these two types may show a Brinell hardness as low as 207, yet I have found this type of steel more difficult to machine than the type of steel similar to "A" containing 2.40 per cent carbon, about 12 per cent chromium with Brinell hardness of 260, and as difficult to machine as the steel "A" with a Brinell hardness of 340.

In general I have failed to notice a relation between the Brinell hardness and the machining characteristics of these steels. In Fig. 1 is shown the chips obtained by machining the two types of steel referred to and the absence of a close relation between hardness and the lowering of carbon is apparent. Fig. 2 shows the microstructure of these two steels.

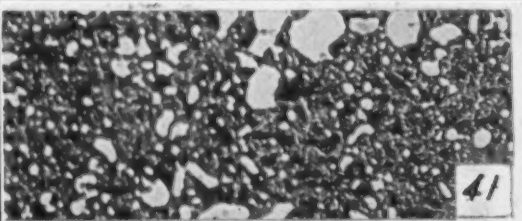
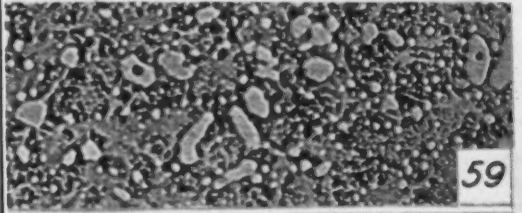
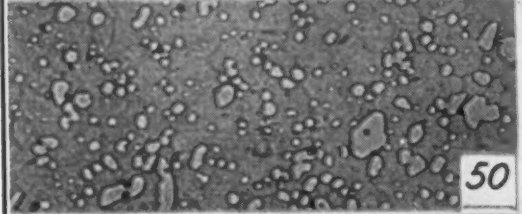
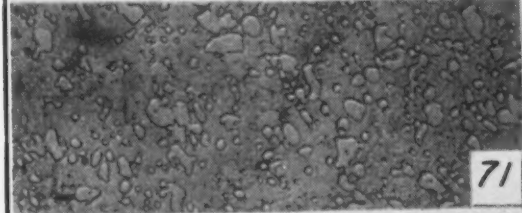
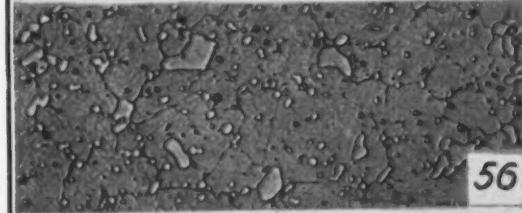
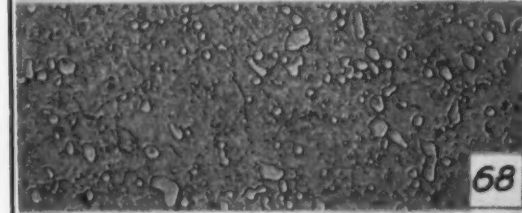
		Carbon	Manganese	Chromium	Vanadium	Cobalt	Max. Rockwell	Hardness at
								2-(Fig. 38)
	41	A	2.38	0.71	12.48	.....	.....	65
	59	D	2.17	0.46	13.43	.....	.....	66
	50	B	2.12	0.31	13.20	0.81	.....	65
	71	H	2.19	0.39	12.01	0.72	0.66	66
	56	C	1.38	0.26	12.20	.....	3.45	63
	68	E	1.60	0.30	16.95	.....	.....	63

Fig. 3—Classification of Steels According to the Persistence of Carbides.

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Possibly there exists a certain structural condition not revealed by Brinell hardness, similar to what at times happens in plain carbon steel, which imparts better machining properties to the metal. An investigation in that direction should prove of great value and any positive results would certainly enable the consumer to use the steel for such purposes where the problem of machining stands in the way.

From Mr. Gill's photomicrographs, I have attempted to classify these steels according to the persistence of carbides after hardening at temperatures that Mr. Gill shows to be temperatures that gave him the maximum hardness for each steel, starting with the steel showing greatest amount of carbide areas, as shown in Table II and made the tabulation (Fig. 3).

From Fig. 3 it will be seen that steel "A" has the greatest amount of carbides and rather in large dimensions and the steels "C" and "E" the least. Apparently the lowering of carbon and addition of vanadium and cobalt results in the lowering of the amount of carbide or greater absorption of carbides in steels containing vanadium. It seems quite reasonable to assume that the effect of vanadium, which is generally conceded to promote greater absorption of carbides in plain carbon steels, is the same in this type of steel.

I would like to ask Mr. Gill whether or not he has noticed any relation between the machining properties of these six types of steels and the degree of carbide segregation in them which greatly vary as shown here.

From this table you will note that the steels C and E, which have lower carbon content than the steel A, have also less carbide segregation, which would lead one to expect that the steels C and E would machine easier than the steel A. In my experience with these types of steels I have found that this is not the case and steel C is not as easily machinable as the steel A.

Author's Reply to Discussion

Mr. Wills' discussion is certainly excellent and should be appreciated since he has discussed the practical side of the hardening of high carbon high chromium steels, particularly in reference to packing, method of handling, etc., which the speaker purposely omitted. The amount of data which we have collected on these steels is quite large and to fully discuss all the practical problems involved is impossible in the scope of one paper, in view of the fact that very little has been previously published on this type of steel. I believe that the heat treatment, including method of handling, annealing, tempering, etc., should be the subject of another paper on high carbon high chromium steels.

In reference to H. G. Keshian's discussion on machinability, we all well know that the high carbon high chromium steels are somewhat difficult to machine. We have not noticed any relation between machinability and the amount of segregate or eutectic present. Apparently, the machinability is dependent upon a combination of hardness and grain size. It appears that if the grain is coarsened the steel will machine easier and

further if the grain is coarsened and the hardness held low machinability is still easier. We have softened some of the steels to as low as 196 Brinell and at this hardness they do seem to machine easier than at about 240 or 250 Brinell. Retaining a hardness of 196 Brinell and coarsening the grain machinability is still easier. All chromium steels machine "gummy"; that is, there is a piling up of the material on the cutting edge of the tool which apparently causes tearing and makes the steel difficult to machine.

In reference to M. A. Grossmann's discussion on the critical points, Mr. Grossmann has well expressed the condition which takes place or the after effect on cooling from different temperatures. Mr. Grossmann, however, has said nothing as to the mechanics of this; that is, we do not know what critical points have been suppressed. You might assume that the critical points that would be suppressed would be the A_1 point and also the point of the changing over of the austenite to martensite, but he does not take into account the carbide transformation and there is excellent evidence that there is a carbide transformation. Now, as to whether or not the carbide transformation takes place at the same time as one of the other transformations, we do not know.

In reference to Mr. Kingsbury's discussion, steel E has a chromium content approximately 3.50 per cent greater than any of the other steels and, as given in the paper, the hardening temperature necessary to obtain maximum hardness was much greater than for any of the other steels, which will be noted on referring to Fig. 31 where a temperature of 1950 degrees Fahr. was necessary to obtain maximum hardness, while no other steel required a temperature higher than 1850 degrees Fahr. to obtain maximum hardness. Therefore, as would be expected, a higher temperature was necessary to obtain maximum austenization than for the other steels. Consequently, a temperature as high as 2150 degrees Fahr. was used for steel E, while none of the other steels was heated to a higher temperature than 2100 degrees Fahr. It cannot, therefore, be assumed that 2100 degrees Fahr. represents maximum austenization, since a much greater degree of austenization was obtained at 2150 degrees Fahr.

The statement that steels B and H could be annealed softest of the steels was not predicated upon the results in Table III but was determined by annealing and re-annealing the steel at a number of different temperatures and at different rates of cooling. As a matter of fact steel D proved the most difficult of the group to obtain a low Brinell reading on annealing. Steel D is somewhat different from steel A in that it contains double the nickel content of steel A. In reference to the maximum hardness that could be obtained, the actual figures are as follows: B—67.4, H—67, A—66.4. This difference does not appear particularly great, yet there is a far greater difference in actual hardness between Rockwell 56 and 67 than there would be between Rockwell 62 and 63. Consequently, as the Rockwell number increases there is a greater actual hardness for each one point of Rockwell.

A NEW METHOD FOR HEAT TREATING HIGH SPEED STEEL

BY HORACE C. KNERR

Abstract

Features of the method described include electrical heating, close temperature control which may be made automatic, the use of a salt bath which does not give off fumes or attack the tools, prolonged container life, absence of furnace deterioration, comfortable working conditions, low heating cost per pound of steel, and the ability to employ full hardening temperatures (in the neighborhood of 2400 degrees Fahr.) without injury to finished surfaces or cutting edges of high speed steel tools.

DEFINITION

THE term "high speed steel," as used in this paper, refers to that group of alloy tool steels which have the property of retaining their cutting efficiency at a dull red heat, ordinarily containing tungsten, chromium and vanadium as the principal alloying elements. There are many commercial brands varying in composition. A typical analysis, and one which represents the greater part of high speed steel used in this country, is as follows: tungsten 18 per cent, chromium 4 per cent, vanadium 1 per cent, carbon 0.65 per cent.

USES

High speed steel has in the past been used principally for tools such as lathe and planer bits which are ground to the desired form after heat treatment and frequently reground during service. Due to its superior cutting properties, even at ordinary speeds, high speed steel is finding an increasingly important application in a variety of finished tools such as drills, milling cutters,

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. The author, Horace C. Knerr, 538 Washington Lane, Germantown, Philadelphia, a member of the society, is consulting metallurgical engineer to Ajax Electrothermic Corp., and others. Manuscript received July 9, 1928.

thread cutters, files, hacksaws, punches, dies and the like, where little or no final grinding may be done after heat treatment, and in which it is therefore necessary to avoid decarburization or damage to the finished surface or fine cutting edges of the tools during heat treatment. Fig. 1.

HEAT TREATMENT

Approved practice for the hardening of high speed steel may be summarized as follows:¹ A—Preheat the tool slowly and uniformly to a temperature of approximately 1500 degrees Fahr. B—Transfer to a furnace whose temperature is 2250 to 2400 degrees Fahr. Allow the tool to reach this temperature rapidly, hold for only a short time. C—Remove and quench the steel in oil or in an air blast, or first in a bath of molten salt or molten lead, held at a temperature of approximately 1100 degrees Fahr. afterward removing and quenching in oil or air. D—Temper by reheating to 1050 to 1150 degrees Fahr. a sufficient length of time (usually one hour or more) and allow to cool in air.

Preheating is for the purpose of avoiding the sudden shock which would occur were the tools heated at once rapidly to the quenching temperature. Heating to the final high temperature, in the neighborhood of 2400 degrees Fahr., is necessary in order to insure the maximum solid solution of the hardening constituents (carbides, etc.) in the steel. If this temperature is not high enough, maximum solution and therefore maximum red hardness and cutting efficiency will not result. There is a tendency for grain growth at the high temperature required in quenching with consequent embrittlement of the steel. Therefore the time at high temperature must be short. To obtain maximum hardening in certain types of high speed steel, notably those containing cobalt, it is necessary to reach a temperature even higher than 2400 degrees Fahr. before quenching.

With the purpose of avoiding damage to finished surfaces and edges, (such as scaling, fusing, burning, pitting and decarburization) which is likely to occur in the ordinary methods of heating above 2300 degrees Fahr., temperatures as low as 2250 degrees Fahr. and even lower, are sometimes employed in treating finished

¹Reference: HANDBOOK, American Society for Steel Treating, Recommended Practice for the Heat Treatment of 18 per cent Tungsten High Speed Steel.

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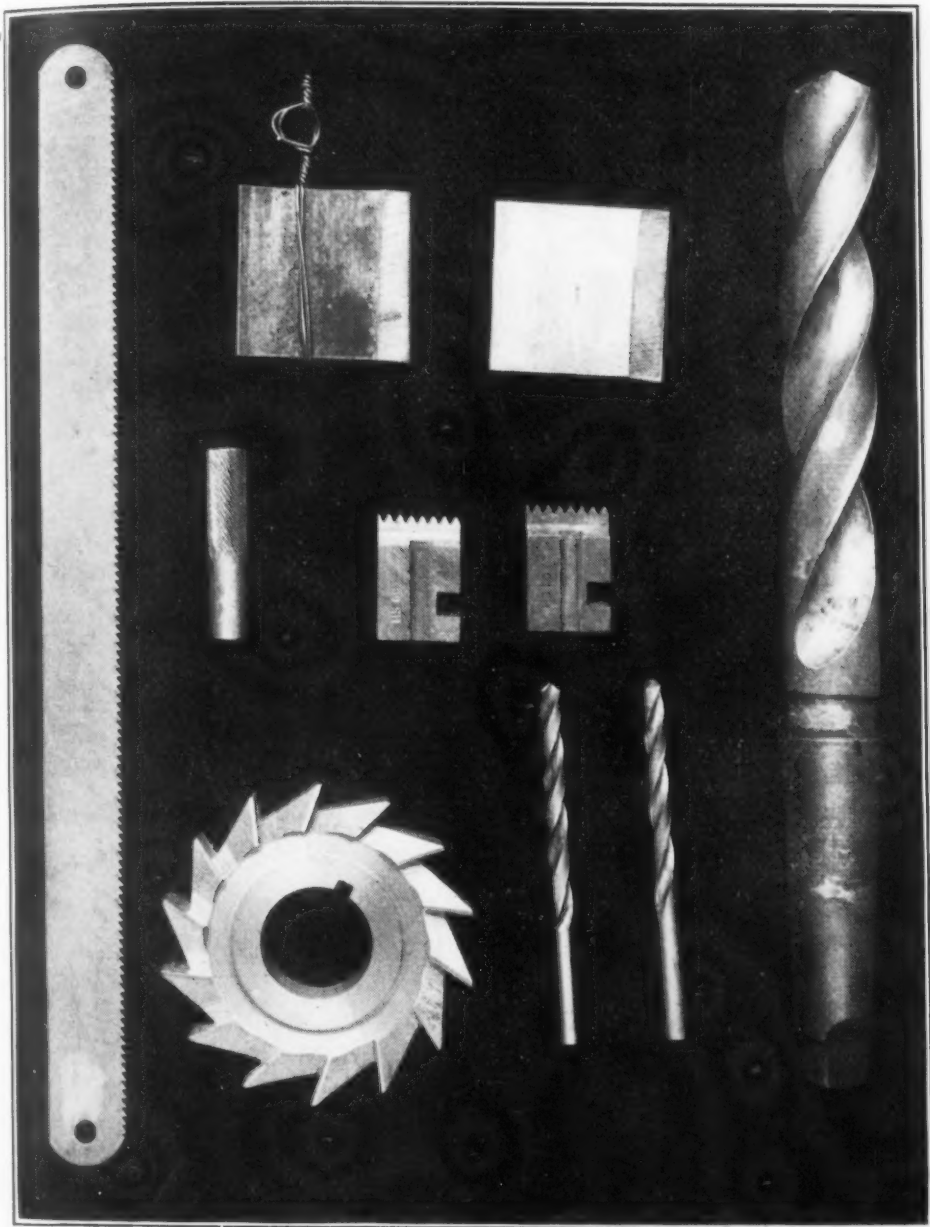


Fig. 1—Typical Finished High Speed Steel Tools. Those on Right Hand Side Photographed After Treatment (2375 Degrees Fahr. Oil Quench) Without Grinding or Retouching. Note Clean Surface and Sharp Cutting Edges.

tools. This cannot produce the maximum solution of hardening constituents. The service of the tool is sacrificed in order to save its surface.

SALT BATHS

In an effort to preserve finished surfaces, and because of other

well-known advantages, recourse has been had to the use of molten salts as a heating medium for high speed steel tools. Salt baths and methods of heating, heretofore employed, have not, however, operated satisfactorily at temperatures in the neighborhood of 2400 degrees Fahr. The salts have not been chemically inert at the desired quenching temperatures, as manifested by fuming, (giving off objectionable vapors), chemical decomposition resulting in change of characteristics, attack of the container, attack of the steel being treated as by pitting, corrosion and so forth, carburization or decarburization of the steel, etc. On account of the attack of the furnace gases on the outside and of the salts on the inside, the pots or crucibles have deteriorated rapidly, necessitating frequent and expensive replacement. (It is not uncommon to use a new steel pot each day).

For these reasons it has not been practicable on a production basis, to heat treat finished high speed steel tools for maximum hardening even in salt baths, and lower temperatures have accordingly been employed. While salt baths may have advantages over the open furnace at temperatures below those which will cause maximum solution of hardening constituents, treatment at such temperatures nevertheless cannot produce the full hardening power of the steel.

PRESENT NEED

There is therefore need for a liquid heating medium or bath which will have satisfactory characteristics at temperatures as high as it is necessary to heat high speed steel in order to obtain maximum hardening effect, and a satisfactory means of heating the bath to the desired temperature without undue deterioration of the furnace or container. The method described herein is believed to have accomplished this result.

LIQUID BATH

A new liquid bath has been developed, which shows excellent characteristics at temperatures as high as 2450 degrees Fahr. The mixture is rather viscous just above its melting point, but at temperatures above 2250 degrees Fahr. it is sufficiently fluid to permit strong convection currents to be set up, which assure temperature uniformity within the container. Even at the highest temperatures (e. g. 2450 degrees Fahr.), a film of molten salt adheres

to the piece of steel when removed, protecting its surface from the atmosphere during transfer to the quenching medium. When uncontaminated from outside sources, the molten salt is neutral to the steel, neither visibly attacking its surface nor causing serious carburization or decarburization. There are no fumes. The cost is moderate.²

EXCLUSION OF OXYGEN

The molten salt has a strong affinity for oxygen and oxides. Scale on the steel is rapidly dissolved and refractories of an oxide nature are attacked. It is therefore necessary to prevent access of oxygen to the bath. This, however, is true of other salt baths used in heat treatment at high temperatures, the absorption of atmospheric or other oxygen being a common cause of decarburization in such baths. The latter difficulty has been avoided by means described further below.

PREHEATING BATH

For preheating the tools it is necessary to have a bath which is liquid below the preheating temperature, 1500 degrees Fahr., which is sufficiently fluid at this temperature to insure uniformity by convection, and which does not harmfully contaminate the high temperature bath when carried over into it as an adhering film on preheated work. Such a bath has been developed and consists of a modification of the high temperature bath. The preheating bath melts at approximately 1400 degrees Fahr. When cold work is inserted, a thick layer of the salts immediately freezes around the tool. This melts off slowly, so that sudden temperature shock is prevented. The preheating bath may be contained in an ordinary pressed steel pot, or preferably in a pot of heat-resisting alloy, cast or pressed. The pot may be heated by gas, oil or electricity as desired. The salt has no noticeable effect upon the pot or the tool at preheating temperature (provided oxygen is excluded).

HEATING HIGH TEMPERATURE BATH

Heating the container for a salt bath required to operate at temperatures in the neighborhood of 2400 degrees Fahr. for con-

* Patent considerations prevent disclosing the composition at this time.

tinuous periods, has heretofore involved serious difficulties, including:

- (a) Attack of the container by the salt bath, or by decomposition products of the bath.
- (b) Attack of the container by products of combustion (or by the furnace atmosphere, when electric heat was used).
- (c) Rapid deterioration of furnace parts and lining, including the resistors when electrically heated.
- (d) Low fuel efficiency due to high sensible heat in the escaping products of combustion when burning gas or oil.
- (e) Difficulty of securing accurate temperature control.
- (f) Unpleasant working conditions due to fumes, gases and heat, etc.

In the present method, heat is generated electrically by means of the well known high frequency induction type furnace. Alternating current of high frequency is passed through a water-cooled copper coil. The pot or crucible to be heated is placed within this coil, thermally and electrically insulated from it. The pot is of electrically conducting material and acts as the secondary of a transformer. It is heated by the induced electric currents generated within it. Fig. 2. The source of high frequency alternating current may be a high frequency oscillator, in which alternating current from the ordinary 220 volt, 60 cycle power line is passed through a transformer which raises the voltage to a point where an arc may be drawn over a mercury bath in a hydrogen atmosphere. A condenser connected in series with this arc produces a resonance effect resulting in alternating current impulses of very high frequency. Fig. 3. For units of large capacity, the required high frequency alternating current may be produced by a motor-generator set.

Pure graphite has been found the ideal material for the heating element. When protected from oxidation, it is unaffected by very high temperatures and has an indefinite life. It is suitable material to use as a secondary in a high frequency inductor at such temperatures. The graphite pot may be used as a container for the present salt bath. This will be referred to herein as Method No. 1. Or, the graphite pot or a ring of graphite, may be used to heat an ordinary metal pot or container, made for example of

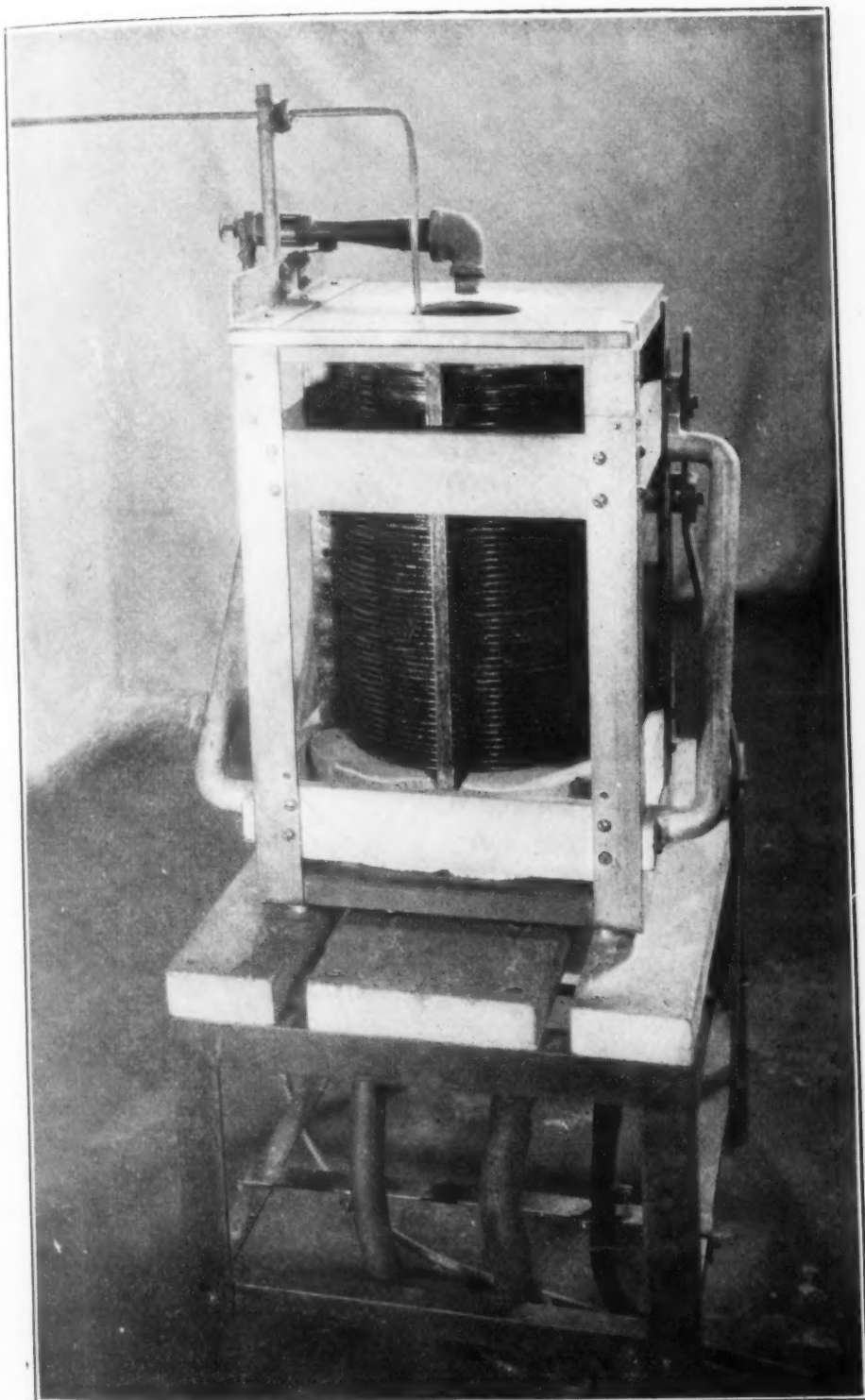


Fig. 2—High Frequency Induction Furnace for Salt Bath.

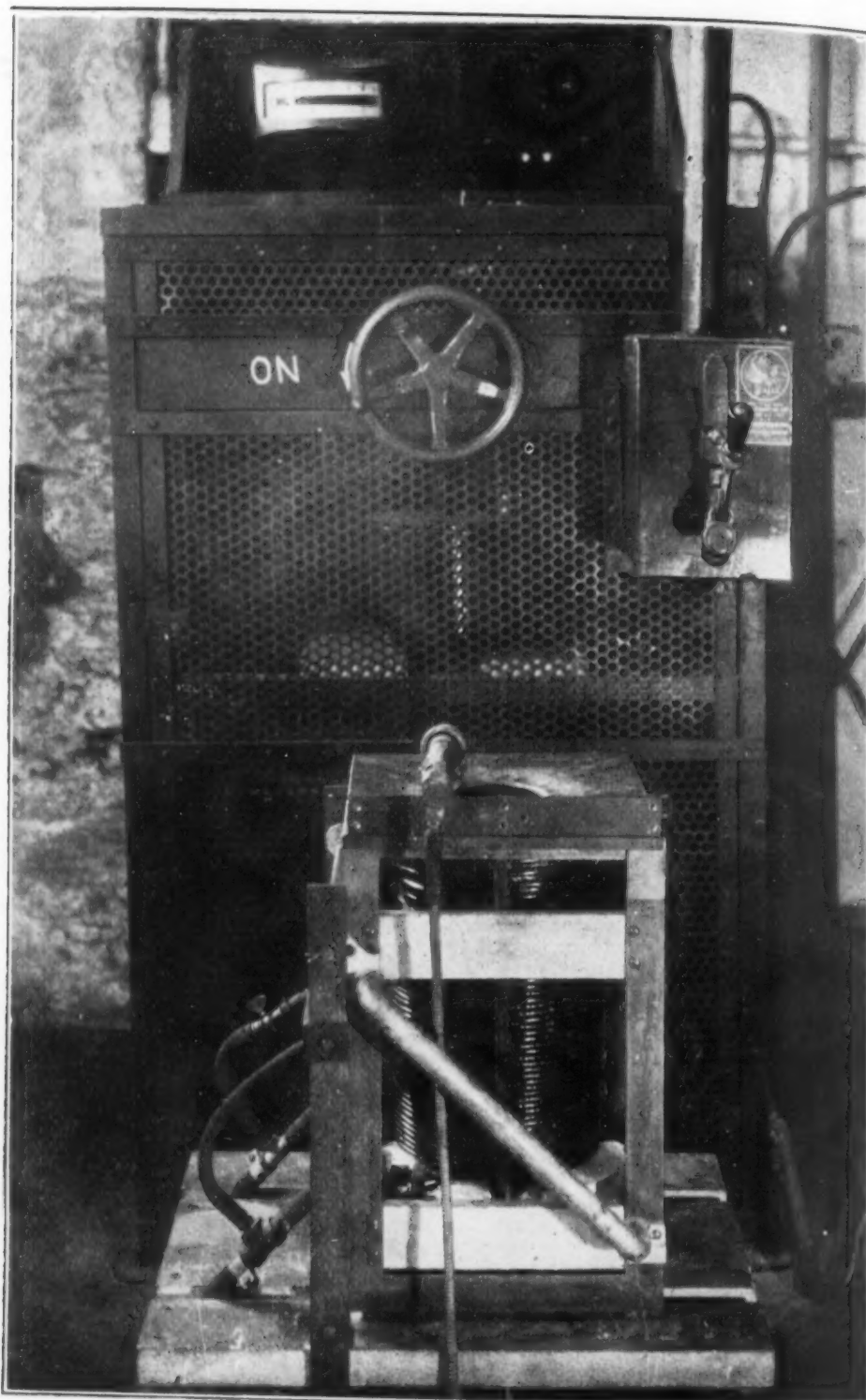


Fig. 3—Induction Furnace and Oscillator for Generating High Frequency Alternating Current, 15 KVA Capacity.

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METHOD NO. 1—GRAPHITE POT AS CONTAINER

The salt bath employed is inert to pure graphite. The outer surface of the pot is protected from oxidation by the insulating material surrounding it. The inner surface, below the salt level, is protected by the bath. Above the level of the salt bath, the inner surface of the pot is protected by means of a ring or liner, which dips below the "water line," thus forming a seal.

It will be understood that no metal, including the tools to be treated, must be allowed to come in contact with the hot walls of the graphite pot, either above or below the surface of the bath, as this would result in fusion due to the absorption of carbon. (The same precaution must be taken in all high temperature salt baths, whether the pot is of graphite or of metal, since, even with metal pots, there is a tendency for a tool to weld to the side of the pot if allowed to touch.) The liner must not touch the pot except near the top edge where the temperature is not high. An annular space is left between the outside surface of the liner and the inside surface of the pot. The pot wall, (which is about 1 inch thick) is counter-bored at its upper rim to receive the liner. This thin portion of the rim extends above the level of the induction coil, and is surrounded by a material of relatively good thermal conductivity, instead of the heat insulating powder which surrounds the lower portion. The rim, therefore, remains at a relatively low temperature. This prevents attack of the liner on its outer surface. See Fig. 4. The active convection currents insure that the bath is of uniform temperature to its top surface.

The graphite pot has of course a strongly deoxidizing action upon the bath. For example, in case of the absorption of oxygen by the bath from the atmosphere, or by dissolving scale from the surface of the steel treated, such oxygen is reduced upon contact with the walls of the pot, passing off as carbon monoxide gas.

METHOD NO. 2—PRESSED STEEL POT AS CONTAINER

A pressed steel pot of ordinary low carbon steel may be placed within a pot or ring of graphite which serves as the inductor or

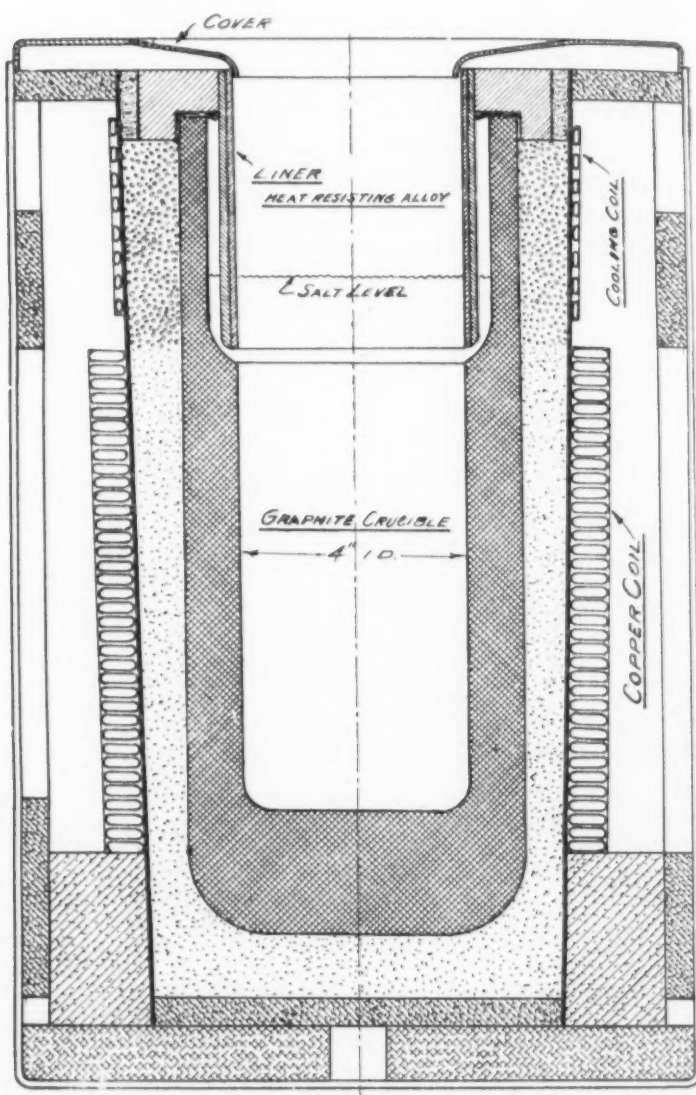


Fig. 4—Vertical Section Through Furnace Showing Construction Using Graphite Pot.

heating element, the latter being lined with a thin layer of non-carbonaceous refractory material such as magnesia, to prevent carburization of the pot. The outer surface of the pot is therefore in a neutral or slightly reducing atmosphere. Deterioration is consequently quite slow. The inner surface of the pot is protected by the salt bath, the portion above the level of the bath being protected from the air by a ring of heat resisting material. It has been found that a liner of high chromium steel stands up well and

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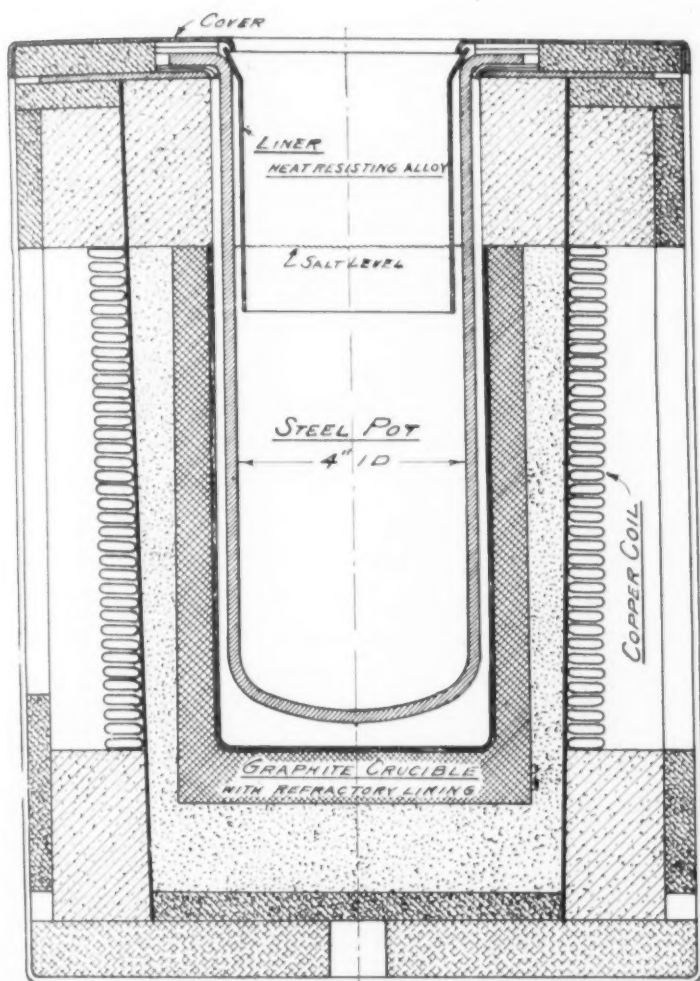


Fig. 5—Section of Furnace Using Pressed Steel Pot.

does not weld to the interior of the steel pot. When worn out, the liner may be replaced at small cost. Fig. 5.

ARTIFICIAL ATMOSPHERE ABOVE BATH

If air is allowed to come in contact with the surface of a salt bath, oxygen may be absorbed, which results in making the bath decarburizing. The heat resisting alloys of the high chromium type probably owe their quality in part to the formation of a highly refractory oxide of chromium. Such an oxide is soluble in the present bath and probably in other baths. The alternate formation and dissolving of this oxide film at the "water line"

would result in a gradual eating away of the shield. Absorption of atmospheric oxygen, and excessive water line attack have been avoided by producing an artificial atmosphere above the bath. One method of doing this consists in introducing a flame from a bunsen burner at the top of the crucible, playing down upon the bath. See Fig. 2. By adjusting the mixture, the atmosphere may be made neutral, slightly oxidizing or reducing at will. If slightly reducing, the atmosphere has a deoxidizing effect upon the bath. On the other hand, if the bath is found to have a carburizing action, as by the picking up of minute particles of carbon from the walls of the graphite crucible, a slightly oxidizing flame will counteract this effect. The presence of a properly adjusted flame, filling the opening of the crucible, has been found to reduce the erosive action of the bath at the "water line" very greatly, thereby lengthening the life of the liner and minimizing attack upon the tools, the rods or wires used to suspend the tools in the bath and the thermocouple used for temperature measurement. This flame also lessens heat losses from the surface of the bath, and helps to soften the surface crust upon remelting the salts after a previous run.

TEMPERATURE MEASUREMENT

Bare thermocouple wires of commercial grade may be used to determine the bath temperature up to 2400 degrees Fahr. and possibly somewhat higher. Small wires have been employed, having no appreciable lag. Deterioration under the protecting atmosphere is slow. The couple may be cut off and the junction renewed at trifling cost. A base metal couple, consisting of a tubular element with the other element inside of it, welded together at the end or an ordinary two-wire couple within a sheath of heat resisting metal may also be used.

Automatic temperature control of the apparatus and a continuous record of temperature are possible and one or both are very desirable in practice.

OPTICAL PYROMETER

An optical pyrometer may conveniently be used to check the thermocouple pyrometer, since it is not subject to deterioration nor contamination by the bath. A tube of high chromium steel, 10 to

12 inches long, closed at the bottom and having a hole about 1 inch in diameter, and a wall about $\frac{1}{8}$ inch thick, is inserted in the bath to a depth (about 4 inches) which insures its bottom end attaining bath temperature. Readings are taken with the optical pyrometer sighted upon the bottom of this tube. This method eliminates errors due to scum or bubbles floating on the surface of the bath, or due to the protective gas flame burning above the bath. "Black body" conditions are approached fairly closely in the tube.

The methods of temperature measurement described above may be used with either the graphite pot or the metal pot.

TILTING

In the event of any accident, such as the dropping of a tool to the bottom of the pot, or of a pot failure, it is desirable immediately to dump the salts. The furnace is therefore arranged on a trunnion, so that it may be quickly and easily tilted to a horizontal position and the salts poured out into a pan provided for the purpose, as illustrated in Fig. 6.

It is not ordinarily necessary to remove the salt after a run, before allowing the pot to cool, as is done in other processes to prevent bursting of the pot by the expansion of the salts on reheating. The present salts soften considerably below the melting point so that internal pressure is relieved. The bunsen flame contributes to the softening of the upper crust. The salts show little solid-to-liquid expansion.

GENERAL CHARACTERISTICS

Output. A 15 KVA oscillator is capable of heating a pot approximately 4 inches inside diameter with a bath about 8 inches deep. This is large enough for the majority of high speed steel tools. For a larger pot a 35 KVA oscillator or a motor-generator may be used. The total maximum actual power drawn from the line, by the 15 KVA outfit, is about 9 kilowatts. (Power factor being about 0.60). This will bring a 4-inch pot to heat treating temperature, starting from cold, in about $2\frac{1}{2}$ hours. Approximately 6 KW are required to hold the pot at 2400 degrees Fahr. About three kilowatts are therefore available for heat treating steel. This

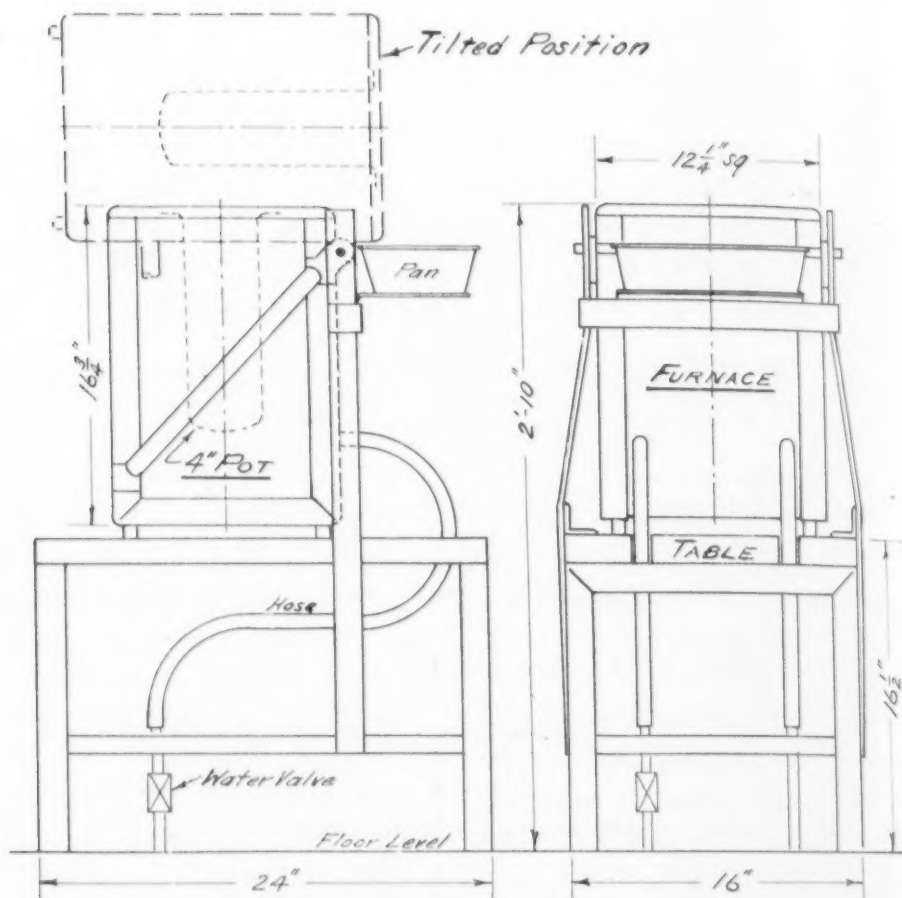


Fig. 6—Method of Tilting Furnace for Dumping Salts, Also Illustrating Size of Furnace for 4-Inch Pot, 15 KVA Capacity Oscillator.

permits a theoretical output of somewhat over 20 pounds of steel per hour, the work having been previously preheated to 1500 degrees Fahr. Pieces ranging from $\frac{1}{2}$ to $1\frac{1}{4}$ pounds have been treated at this rate. The overall power consumption was 0.45 KWH per pound of steel, costing less than one cent per pound at a current charge of two cents per KWH.

TEMPERATURE REGULATION

Power input into the furnace is controlled by means of a hand wheel which varies the spark gap and permits of rapid and close regulation of temperature. See Fig. 3. While automatic temperature control has not been applied at date of writing, it would appear to offer no difficulties, involving merely the application of methods and apparatus now available.

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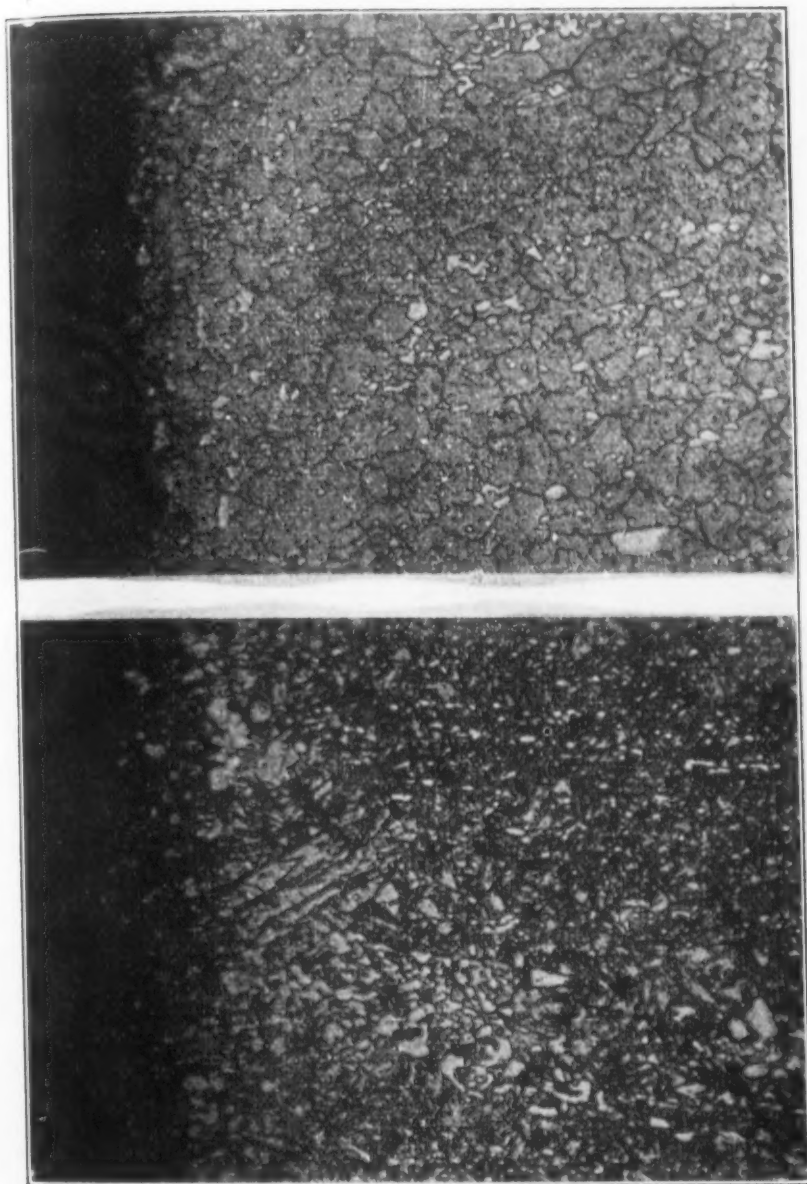


Fig. 7—Microsection at Exposed Surface. $\times 500$. Upper—After Quenching. Lower—After Tempering.

SPACE AND WORKING CONDITIONS

The floor space required by the furnace proper is very small, being about 18 x 24 inches overall for a 4-inch pot. See Fig. 6. Additional space is of course required for the oscillator. See Fig. 3. Working conditions around the furnace are comfortable, the

outside of the furnace being at room temperature because of the water cooling. The only source of radiant heat is the actual pot opening and the bunsen flame within it. The operator is protected from contact with electrical circuits.

RESULTS

Finished tools of various types have been heat treated at 2350 to 2400 degrees Fahr. without any mark upon the surface other than a slight discoloration. Sharp cutting edges were practically unaffected and retained file hardness. No pitting, scale, or other surface defects occurred when the treatment was properly carried out. There was no warping, provided of course, internal strains had been removed from the tools before treatment. These tools were quenched in oil and tempered either in a salt bath or an electric muffle furnace at 1100 degrees Fahr. for from 1 to 4 hours. Rockwell hardness of 62 to 65 C was obtained on the surface after tempering.

SERVICE TEST OF TOOLS

Drills, thread cutters, files, file cutting chisels and lathe tools treated by this method have been tested in service. Results compared favorably with tools treated in the open furnace and ground, and were superior to tools treated in salt baths at the customary lower temperatures.

MICROSTRUCTURE

Microsections taken at exposed surfaces and edges after treatment showed no visible decarburization. See Fig. 7.

POT LIFE

An ordinary pressed steel pot, 4-inch diameter, 12 inches deep, $\frac{1}{4}$ -inch wall, has been operated at temperatures between 2300 and 2450 degrees Fahr. for a total of 20 hours (4 heats) and is still in excellent condition. Graphite pots have operated without serious deterioration until destroyed accidentally.

CONCLUSION

While the method herein described will undoubtedly go through a period of development and improvement, as in all new

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industrial processes, it is believed that the principles are sound and that the process offers a real advance in the art of heat treating high speed steel. The increase in service produced by the more complete hardening of high speed steel tools which satisfactory treatment at the higher temperature makes possible, should be the source of economies and increased production in machining operations and should result in extending the field of usefulness of high speed steel.

The development work was done in the Metallurgical Laboratory of Temple University.

DISCUSSION

Written Discussion: By W. Paul Eddy, Jr., Brown-Lipe-Chapin Gear Co., Syracuse, N. Y.

Many toolmakers find it advisable to harden fine-edged tools of high speed steel on the low side of the recommended temperature range, in order to save the edges. Others, however, use the lower temperatures for certain types of high speed steel tools, though at some sacrifice of cutting efficiency or wear resistance, in order to retain greater toughness.

The bath method of heating is undoubtedly good from the standpoint of production, in that, besides being inherently fast, it is conducive to the establishment of uniform heating intervals for tools of a size and therefore to the elimination of individual judgment, it reduces overheating of edges and thin sections, and it provides, in the case of salt, protection of all surfaces of the tools when being transferred to the quench.

Owing to the fact that salt mixtures for high temperature work are, in general, very resistant to the action of commercial cleaning compounds, it is customary to quench tools heated in such salts in another lower melting salt mixture which exerts a solvent action on the high temperature salt. This salt quench, usually at about 1100 degrees Fahr., is not in itself objectionable—in fact, it is preferable to many—but it means that in addition to the high temperature salt carried off on the work there is a considerable consumption of the quenching salt (the combination of the two salts results in a sludge which settles to the bottom of the quench pot). It is possible that by applying electrolytic methods to the cleaning of the tools the consumption of the quenching salt may be either greatly reduced (using a quenching salt inert to the high temperature salt) or entirely eliminated (using an oil or air quench). On the other hand, many are glad to accept the salt consumption as a necessary evil of salt bath hardening merely because of the protection to tool surfaces offered by the salts.

High frequency induction offers a very attractive method of heating a muffle furnace, either pot or oven type, as well as a salt bath. Some salt

mixtures, however, are not as inert to high speed steel when heated in an induction furnace as when heated in a gas or oil-fired furnace; this may be due to electrolytic actions set up in the bath by electric currents resulting from incomplete absorption of energy by the bath container. The difference between the losses of metal incurred by fuel and induction heating, while requiring rather precise comparison to measure, is relatively large. Preliminary tests with Mr. Knerr's new salt mixture, however, indicate that loss of metal from the work in the induction furnace is no larger than has heretofore been expected in fuel-fired salt bath furnaces.

The Ajax-Northrup type of high frequency induction furnace is, in spite of considerable heat being carried off in the cooling water, unquestionably very efficient and inexpensive to operate. Mr. Knerr's figures on overall power consumption in heating tools are attractively low; in practice, however, one seldom attains the theoretical.

Through the co-operation of the company with which the writer was associated and Ajax Electrothermic Corp., the writer has been able to conduct, during the past year and a half, a number of experiments on induction heating of various salt mixtures and muffles. As might be expected, results were occasionally discouraging; but, in general, successful application of induction heating to high speed steel hardening has been surely indicated. Inasmuch as larger containers (6 to 10 inches in diameter) than those described in Mr. Knerr's paper were used, and as power was converted with either a 35 kilovolt ampere oscillator or a motor-generator set, it may be of interest to give briefly a few typical results.

Using a pressed steel cylindrical container, with $\frac{1}{4}$ inch walls, 6-inch inside diameter and 11 inches deep, and obtaining power through a 35 kilovolt ampere oscillator, high temperature salt was melted and heated to 2350 degrees Fahr. from room temperature, in 60 minutes, drawing $22\frac{1}{2}$ kilowatts from the line. To hold the temperature of this bath constant at 2345 degrees Fahr. with the container uncovered required $14\frac{1}{2}$ kilowatts. The bath was $9\frac{1}{2}$ inches deep.

At another time, with practically the same setup, a bath 10 inches deep was melted and heated to 2250 degrees Fahr. in 80 minutes, drawing 19 kilowatts.

Again, the time to melt and heat a 10 inch deep bath to 2250 degrees Fahr., using 16 kilowatts, was 110 minutes.

It may also be noted that a 12 inch deep bath of a quenching salt, in a pressed steel container 10 inches in diameter by 16 inches deep, was melted and heated to 1150 degrees Fahr. in 130 minutes, using a 35 kilovolt ampere oscillator drawing $11\frac{1}{2}$ kilowatts, and that $5\frac{3}{4}$ kilowatts held this bath at a constant temperature of 1305 degrees Fahr.

Lest there appear to be discrepancies between the above figures and those given in the paper under discussion, it should be understood that Mr. Knerr, in his later work, has undoubtedly been able to improve upon the efficiency of electrical coupling between coil and container and to obtain more nearly complete energy absorption by the load. Nevertheless, it appears, from the data given above, that a 35 kilovolt ampere oscillator has

ample capacity to run both the high temperature and the quench bath mentioned, and would heat the two baths simultaneously from cold to their respective operating temperatures within a reasonable time (about two

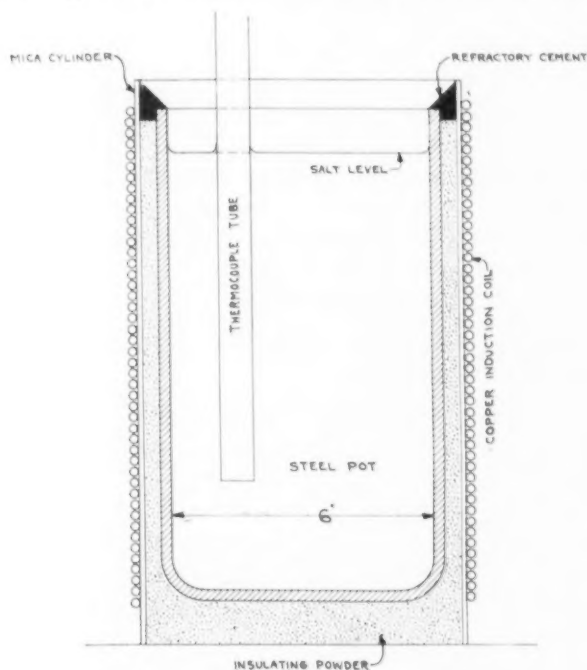


Fig. 1—Cross-Section of Furnace with Pressed Steel Pot.

hours). The maximum power obtainable from such a converter depends on several factors, but under favorable conditions amounts to about 27 kilowatts.

All temperatures reported above represent observations taken with shielded thermocouples whose hot junctions were, in every case, about 3 inches above the bottoms and approximately halfway between the side walls and centers of the bath containers.

Fig. 1 is a sketch of the general layout in cross-section. The only fundamental difference between this and Figs. 4 and 5 in Mr. Knerr's paper is that the top of the coil in Fig. 1 is above the level of the bath surface and approximately on a level with the top of the container.

The writer believes that Mr. Knerr's remarkable paper begins a new march of progress along the lines of electrical heat treatment of metals.

Written Discussion: By S. C. Spalding, Halcomb Steel Co., Syracuse, N. Y.

The author is to be congratulated on this paper which is on a subject of such timely interest to so many of us. I believe we all will agree that there is need for better methods for high speed steel hardening. Since we graduated from the blacksmith forge fire to the oil and gas semi-muffle furnaces there has been quite a period of practically no prog-

ress. Liquid bath methods have been tried off and on during this period with rather indifferent success, the main cause of failure being the limitations of the pot or container which has made it impossible to do the hardening at temperatures much over 2200 degrees Fahr. which are unquestionably too low. There is also some indication within the last year of the development of a successful electric carbon resistor furnace. I believe that the liquid salt bath however offers a most attractive method if it can be successfully worked out. Some of the difficulties to be overcome are obtaining a bath which will be inert to the steel, one which will not vaporize too readily at these high temperatures, and a pot which will have a reasonable life. All these points the author states his method overcomes.

We sincerely hope that he has and that he will soon put this equipment on the market in a commercial way.

Written Discussion: By A. H. Kingsbury, Crucible Steel Co. of America, Atha Works, Harrison, N. J.

So far as my experience has shown, this method is new and unique and possibly may be the long sought answer to many of the serious problems confronting the hardener of high speed steel.

Under the heading "Results," the author claims that this process does not result in warping. Assuming by warping that he means no apparent change had occurred in the original alignment of the axes of the tools; it has been quite clearly established that the proper method of heating in the open fire will result in no warping.

To those who are directly connected with the hardening of high speed steel, it will undoubtedly be of considerable interest to know whether or not form or threading tools, hardened by this process, have been subjected to test by the Comparator or some similar method. If they have, and it is found that on hardening no change has taken place in the form of the tool, then it appears that this process represents a valuable discovery.

Oral Discussion

R. W. WOODWARD: Mr. Knerr's paper has been very interesting to me and a few questions arose concerning it. In the first place, I would like to inquire regarding the frequency of the oscillations, particularly whether the natural frequency or any prominent harmonics come in the same spectrum used for radio purposes.

In regard to the mechanism of heating, does the graphite shell afford a complete inductive shield to the steel which is being heated? In other words, is any inductive heating taking place in the steel itself? Naturally, the operation of the method would entail mechanical loss of the salt, and should the operator fail to replace the salt soon enough, that is, allowing it to get below the protective lip, how soon would the complete furnace burn out?

Author's Reply to Discussion

Through the courtesy of *Iron Age* I have been advised that there is in this country annually produced about 13,000 tons of high speed steel. That figure has been roughly checked in another way. A promi-

ment steel man in Philadelphia estimated that about 200 tons of high speed steel is consumed in the Philadelphia territory each year. A leading manufacturer of small tools in New England uses about one ton a day.

I very much appreciate the written and oral discussions. The interest which has been shown in this subject proves it to be a live one. The several different methods which are being developed at this time all seem to have good points.

As to Dr. Woodward's questions, engineers of the Ajax Electrothermic Corp. tell me that for the oscillator, the frequency is rather indefinite and may run anywhere from 10 to 30 thousand cycles. The mercury arc is, of course, inside of a cast iron container and that is entirely surrounded by a sheet metal cage. The apparatus has been operated close to radio receivers without any apparent harm. The motor-generator sets, used where larger output is desired, have fixed but lower frequencies and also do not seem to cause radio interference.

If any inductive heating of the tool occurs inside of the graphite pot or shell it is not sufficient to be of importance. Direct inductive heating of the tool is not desirable as it does not act uniformly in a piece of irregular shape.

The salt which is carried out mechanically as a protective adherent film on the tools must be replaced from time to time. With care this can be done without danger to the operator even while the bath is hot. This method is, of course, not absolutely fool-proof, nor do I think any other method of heat treating high speed steel is. If the operator lets the salt level go below the shield, attack will then begin on the pot and pot life will be sacrificed. I do not know how long the pot will last without the shield, but it certainly will not last as long as with the shield,—that is what the shield is there for.

Mr. Eddy, in his written discussion, has brought out a number of advantages of the method, which were not included in the paper because of lack of space.

A fundamental difference between Mr. Eddy's arrangement, shown in his Fig. 1, and the author's, shown in Figs. 4 and 5 of the paper, resides in the fact that Mr. Eddy used a steel pot to serve simultaneously as resistor and container for the salt bath. Tests made by the writer showed a resistor of graphite to be much more efficient than steel at the temperatures employed. This resistor may be used either as container for the bath as shown in Fig. 4, or as a source of heat for the steel pot placed within it, as in Fig. 5.

The penetration of flux to the interior of a graphite shell is slight. The internal steel-pot acts as an additional shield. Therefore no troublesome induction occurs in a tool which has been preheated before placing in the high temperature bath, since the tool is made non-magnetic in the preheating process. This would avoid the electrolytic attack by the salts, due to induced currents, mentioned by Mr. Eddy.

With respect to the removal of adhering salt after oil quenching, a water solution has been found which readily accomplishes this.

The theoretical figures for power consumption and hourly output mentioned in the writer's paper were checked by actual production, as stated under "General Characteristics" in the paper. Mr. Eddy's figures for heating rates when using a steel pot as resistor with a 35 KVA oscillator, are exceedingly interesting, especially in view of the fact that a graphite resistor has been found much more efficient than one of steel and will therefore heat up more quickly and afford a greater output in pounds of steel treated per hour.

His plan of running both the high temperature bath and the preheating bath from the same oscillator appears to present some complications with respect to the method of temperature control. The writer believes that the preheating bath could be operated more efficiently by means of an independent electric resistance furnace or a gas fired furnace, and that better and more satisfactory control would be obtained by regulating each bath separately.

Mr. Kingsbury mentions the question of warping and of the accuracy of thread cutting tools after treatment. When long tools of small diameter, such as drills, are heated in a fuel fired furnace, they are usually placed horizontally. This contributes to warping. In the salt bath furnace they are suspended vertically, which tends to avoid warping. Optical tests of thread cutting tools made by Mr. Eddy showed less change of thread form than obtained by him with previous methods.

It is the writer's hope that this method will be developed to a commercial state within a reasonable time, but it will be necessary, of course, to continue through a preliminary stage, including the actual heat treatment of a variety of tools, in reasonable quantities and under varying conditions, before the method can be said to be finally established. The co-operation of those interested in this work will be welcomed and appreciated.

Editor's Note: Following Mr. Knerr's presentation of his paper, Professor W. B. Hall of Yale University presented a discussion dealing with the subject of hardening high speed steel. The discussion, however, described another furnace for the same application, and inasmuch as it did not discuss Mr. Knerr's paper directly, has been withdrawn for later presentation as a separate paper. Messrs. R. M. Keeney and A. N. Otis participated in discussion of Professor Hall's contribution.

CUTTING QUALITIES OF AN ALLOY STEEL AS INFLUENCED BY ITS HEAT TREATMENT

BY O. W. BOSTON AND M. N. LANDIS

Abstract

The results of a series of experiments made in an endeavor to determine the value of four methods of estimating a machinability rating of an S.A.E. 6140 steel under various heat treatments are presented. The cutting qualities are expressed in four ways: a cutting rating as influenced by the tool life and finish secured as observed while a turning tool was cutting under standardized conditions, the torque and thrust of a $\frac{3}{4}$ inch drill cutting under standardized conditions as measured on a drill dynamometer, and the time of a $\frac{1}{4}$ inch drill to penetrate $\frac{1}{4}$ of an inch while cutting under standardized conditions.

The materials were given a number of single and double heat treatments so as to obtain various annealed structures, as well as various degrees of spheroidizing, in which the pearlite is divorced into its constituents, ferrite and cementite.

It is shown that pure annealing does not give the best machining qualities, but that steels cut best when the spheroidizing is greatest.

THE object of this paper is to present the results of a series of experiments made in an endeavor to determine the value of four methods of estimating a machinability rating by use of S.A.E. 6140 steel under various heat treatments.

The cutting qualities are expressed in four ways: the cutting rating, drill torque, drill thrust, and drill penetration.

THE MATERIAL TESTED

The material used in these experiments consisted of a number of different bars of open-hearth, chromium-vanadium steel con-

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. Of the authors, who are members of the society, O. W. Boston is professor of shop practice at the University of Michigan, Ann Arbor, Mich., and M. N. Landis is a member of the firm Landis and Landis, metallurgists, of Chicago. Manuscript received July 2, 1928.

forming to the specifications S.A.E. 6140. The chemical analysis of each test bar is shown in Table I. These steels are divided into two main lots, called A and B.

Lot A consists of two distinct analyses; bars 237, 246, 251, and 255 have higher carbon, manganese, phosphorus, sulphur, and chromium contents than bars 238, 248, 252, and 256. Both, however, have rather high carbon content for S.A.E. 6140. The two were run in parallel in treating them.

Lot B consists of a number of different steels, but again they are closely allied in their analyses and it is doubtful if the slight differences have entered very considerably into the various cutting results.

HEAT TREATMENTS EMPLOYED AND THE STRUCTURE OBTAINED

The heat treatments used in these experiments are listed in Table II in the order in which they were conducted.

The various temperatures generally accepted for treating steel of this type are as follows:

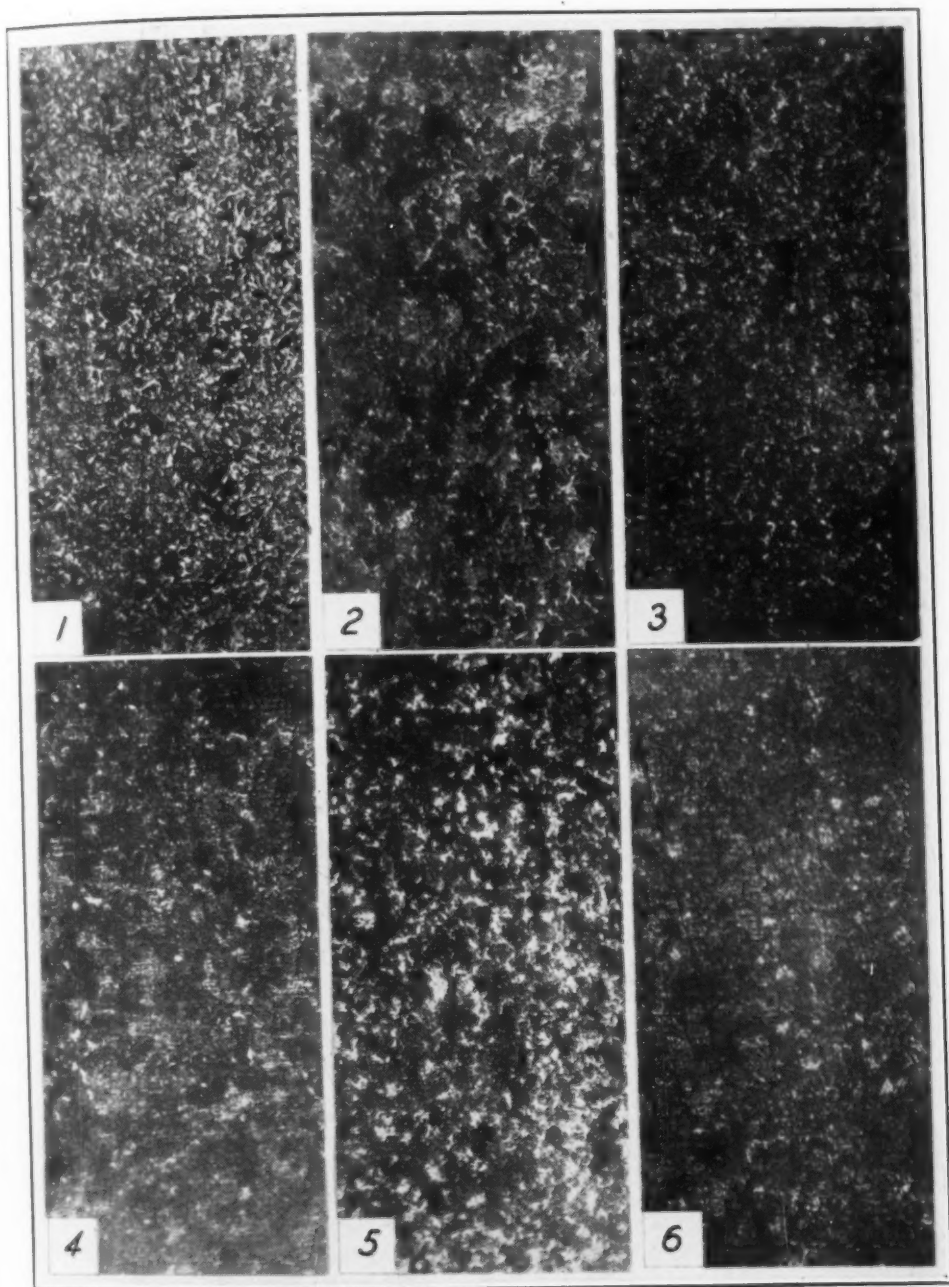
For normalizing:	Heat to 1650-1750 degrees Fahr. Cool in air
For quenching:	Heat to 1550-1650 degrees Fahr. Quench as desired
For machining:	Reheat to 1250-1350 degrees Fahr. after normalizing

As the carbon content of the steels was near the top of the range for S.A.E. 6140 steel, and in the absence of critical point determinations, the lower normalizing temperatures, namely 1650 and 1550 degrees Fahr., were chosen. The temperature range listed as desirable for machining purposes was thought to be low, so a range of 1400 to 1475 degrees Fahr. was arbitrarily chosen.

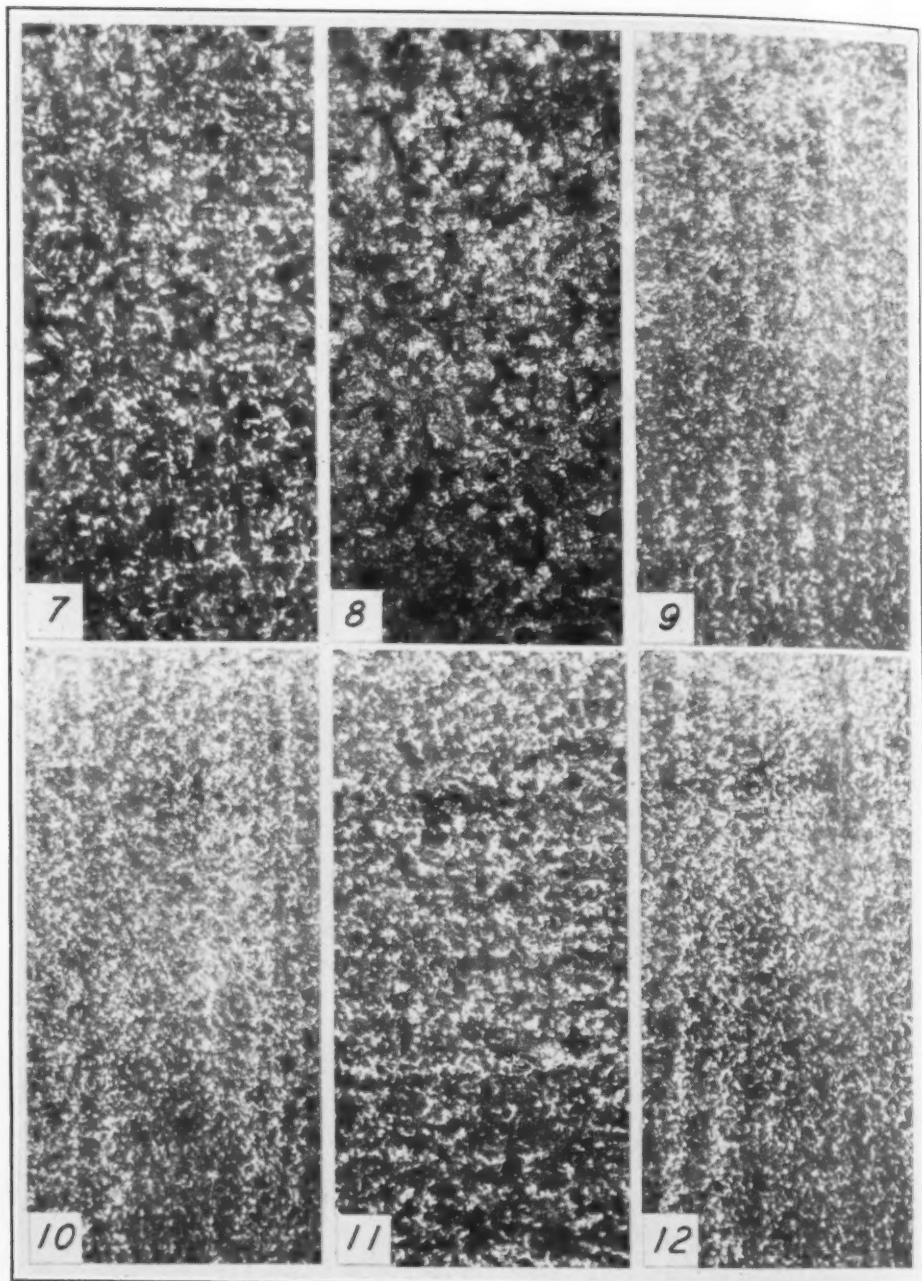
As it was desirable to have a steel available for machining, the procedure consisted of single and double slow cooling treatments. The single treatments were for the purpose of obtaining an annealed steel and the double treatments to obtain a spheroidized steel. It was assumed that the treatment giving the greatest divorcement of the pearlite into its constituents ferrite and cementite, spheroidizing, would give the best machinability.

Photomicrographs of all the steels tested, with their heat

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Photomicrographs of S. A. E. 6140 Steel. Fig. 1—Bar 237. Heat Treatment, as Received. Structure Shows a Semispheroidized Condition. Cutting Rating, Good (90 Per Cent). Fig. 2—Bar 238. Heat Treatment, as Received. Annealed Structure of Ferrite and Pearlite with Practically no Divorcement of Pearlite. Cutting Rating Very Poor (40 Per Cent). Fig. 3—Bar 246. Heat Treatment No. 1. Annealed Structure with Slight Tendency to Spheroidize. Cutting Rating Poor (50 Per Cent). Fig. 4—Bar 248. Heat Treatment No. 1. Annealed Structure with Less Tendency to Spheroidize than No. 246. Cutting Rating Poor (50 Per Cent). Fig. 5—Bar 251. Heat Treatment No. 2. Structure Shows Material has had a Previous Treatment, as it Shows a Slight Spheroidizing. Cutting Rating Poor (50 Per Cent). Fig. 6—Bar 252. Heat Treatment No. 2. Structure Shows More of True Anneal. Cutting Rating Poor (50 Per Cent). All Photomicrographs $\times 100$.



Photomicrographs of S. A. E. 6140 Steel. Fig. 7—Bar 255. Heat Treatment No. 3. Structure Shows Semispheroidized Condition. Cutting Rating Good (90 Per Cent). Fig. 8—Bar 256. Heat Treatment No. 3. Structure Shows Semispheroidized Condition Slightly More than No. 255. Cutting Rating Good (90 Per Cent). Fig. 9—Bar 281. Heat Treatment No. 4. Structure Shows Drawing Lines and Slight Spheroidizing. Cutting Rating Poor (50 Per Cent). Fig. 10—Bar 282. Heat Treatment No. 4. Structure Shows More Spheroidizing than No. 281, but the Drawing Lines, or Banded Structure from Drawing, are in Evidence. Cutting Rating Poor to Fair (60 Per Cent). Fig. 11—Bar 283. Heat Treatment No. 5. Structure Shows Banded Structure of Drawing with the Start of Spheroidizing. Cutting Rating Very Poor (40 Per Cent). Fig. 12—Bar 284. Heat Treatment No. 5. Structure Very Similar to No. 283, with the Spheroidizing Carried Somewhat Farther. Cutting Rating Fair (70 Per Cent). All Photomicrographs $\times 100$.

Table I
Chemical Analyses of the Alloy
Steels, S.A.E. 6140

	Bar No.	Chemical Analyses, Per Cent				
		Carbon	Manganese	Phosphorus	Sulphur	Chromium Vanadium
Lot "A"	237	0.48	0.76	0.016	0.021	0.95 0.15
	238	0.47	0.73	0.014	0.018	0.93 0.15
	246	0.48	0.76	0.016	0.021	0.95 0.15
	248	0.47	0.73	0.014	0.018	0.93 0.15
	251	0.48	0.76	0.016	0.021	0.95 0.15
	252	0.47	0.73	0.014	0.018	0.93 0.15
	255	0.48	0.76	0.016	0.021	0.95 0.15
	256	0.47	0.73	0.014	0.018	0.93 0.15
Lot "B"	281	0.44	0.63	0.015	0.023	1.05 0.16
	282	0.43	0.63	0.016	0.020	1.05 0.16
	283	0.44	0.63	0.015	0.023	1.05 0.16
	284	0.43	0.63	0.016	0.020	1.05 0.16
	285	0.42	0.62	0.015	0.022	1.06 0.16
	286	0.44	0.63	0.015	0.023	1.05 0.16
	287	0.43	0.63	0.016	0.020	1.05 0.16
	272	0.41	0.60	0.015	0.016	1.03 0.16
	273	0.45	0.62	0.013	0.014	1.06 0.16
	274	0.43	0.60	0.014	0.020	1.04 0.17
	277	0.42	0.62	0.015	0.022	1.06 0.16
	278	0.43	0.63	0.016	0.020	1.05 0.16
	280	0.42	0.62	0.015	0.022	1.06 0.16
	275	0.42	0.62	0.015	0.022	1.06 0.16
	276	0.44	0.63	0.015	0.023	1.05 0.16
	279	0.43	0.63	0.016	0.020	1.05 0.16
	352	0.44	0.60	0.015	0.023	1.06 0.16
	353	0.43	0.61	0.015	0.023	1.06 0.16
	364	0.43	0.60	0.014	0.020	1.04 0.17
	427	0.44	0.60	0.015	0.023	1.06 0.16
	428	0.43	0.61	0.015	0.023	1.06 0.16
	429	0.41	0.60	0.015	0.016	1.03 0.16
	430	0.41	0.60	0.015	0.016	1.03 0.16

treatments listed by number according to Table II are shown in Figs. 1 to 31, inclusive. A brief discussion of each structure is given primarily to show whether they are spheroidized or annealed, as this is the essential difference between them, each having been given a slow cooling treatment. The cutting rating is also indicated for each steel. All samples were etched with nitric acid and are shown magnified 100 times.

THE MECHANICAL TESTS

The mechanical tests used in these experiments were confined to the cutting rating, the drill torque and thrust, drill penetration, and Brinell hardness number.

The cutting rating is expressed in per cent. This cutting rating depends on the shape of the chip of a lathe turning tool, (the amount of material cut, and the conditions of the cut surface) as observed under actual cutting conditions. The cutting speed was

Table II
Heat Treatments Given the
Alloy Steels, S.A.E. 6140

No.	Heat Treatment
1	Heat to 1650 degrees Fahr. and cool in furnace to 1400 degrees Fahr. and air cool
2	Heat to 1650 degrees Fahr. and cool in furnace
3	Heat to 1650 degrees Fahr. and cool in furnace
4	Reheat to 1475 degrees Fahr. and cool in furnace
5	Heat to 1650 degrees Fahr. and cool in air
6	Reheat to 1500 degrees Fahr. for 3 hours and cool in furnace
7	Heat to 1550 degrees Fahr. Hold for 4 hours and then cool in furnace
8	Heat to 1425 degrees Fahr. Hold for 8 hours and then cool in furnace
9	Heat to 1550 degrees Fahr. Hold for 3 hours and then cool in furnace. Then cold drawn with 1/16 inch draft
10	Heat to 1650 degrees Fahr. Hold for 1 hour and air cool. Reheat to 1400 degrees Fahr. and hold for 12 hours and cool in furnace
11	Cold drawn stock as received
12	Heat to 1550 degrees Fahr. and cool in furnace. Reheat to 1425 degrees Fahr. and hold for 3 hours, then cool in furnace.
13	Number 10 cold drawn with 1/16 inch draft after heat treatment

150 feet per minute, the depth of cut was $\frac{1}{8}$ inch, and the feed was 0.080-inch per revolution. The test was made dry and cutting continued until the tool was destroyed. The cutting was rated as follows:

	Per Cent
Very good	= 100
good	= 90
fair to good	= 80
fair	= 70
poor to fair	= 60
poor	= 50
very poor	= 40

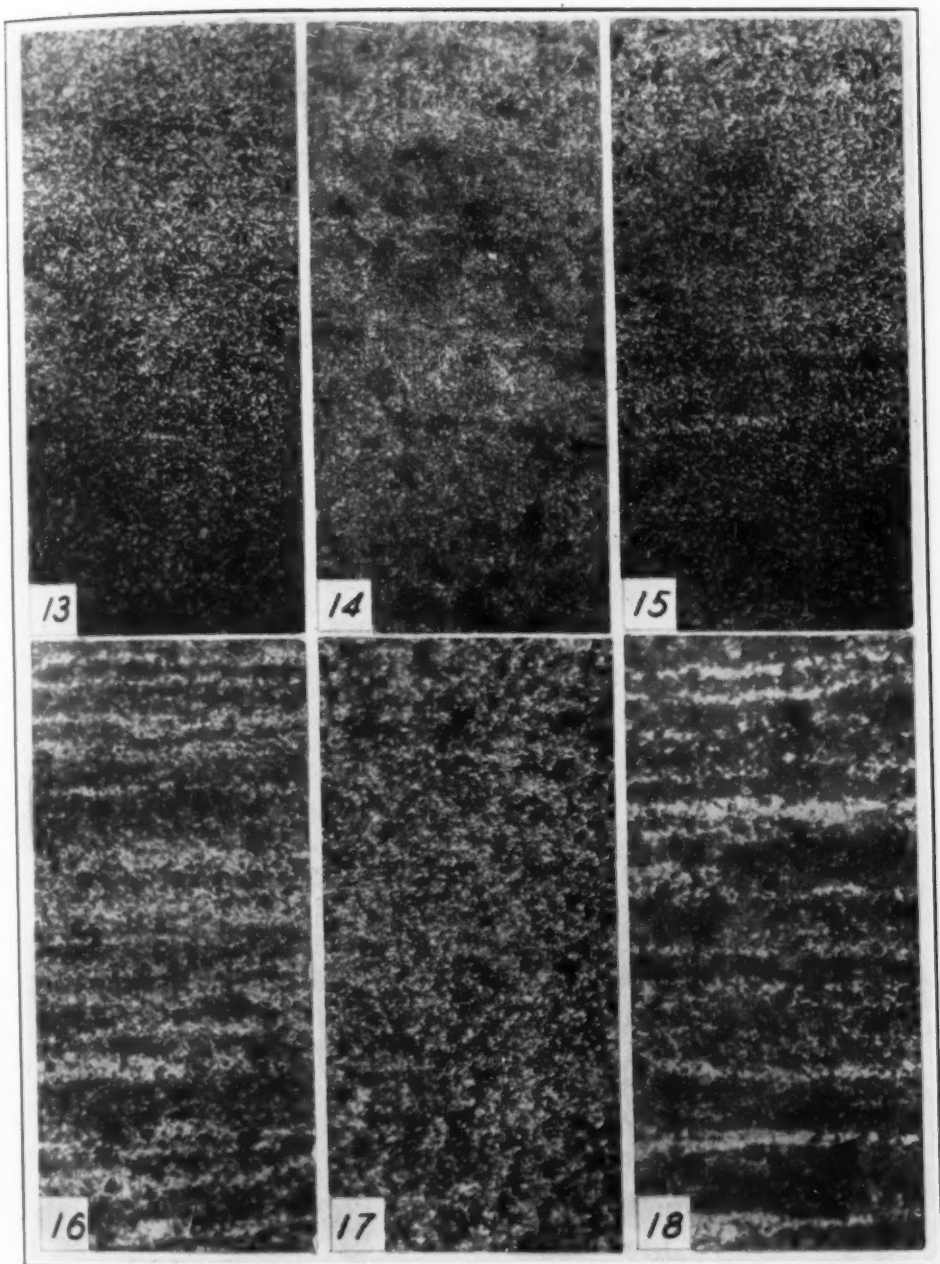
These values are, of course, based upon the judgment of the observer and may or may not represent that which it is supposed to.

The drill torque is expressed in foot-pounds and the thrust is expressed in pounds. The values were obtained in these experiments by drilling the material on the end, that is, parallel to the axis of the bar. The drill used had a $\frac{3}{4}$ -inch diameter and was made of high speed steel. It was rotated at 152 revolutions per minute and had a feed of 0.012 inches per revolution. The drill was ground on a Blau drill grinder and had a clearance angle of 3 degrees 48 minutes, and a flute helix of 30 degrees. All tests were conducted with the one grinding and the drill appeared to be in very satisfactory condition at the end of the tests, as tests made at the beginning could be checked after all drilling tests were completed.

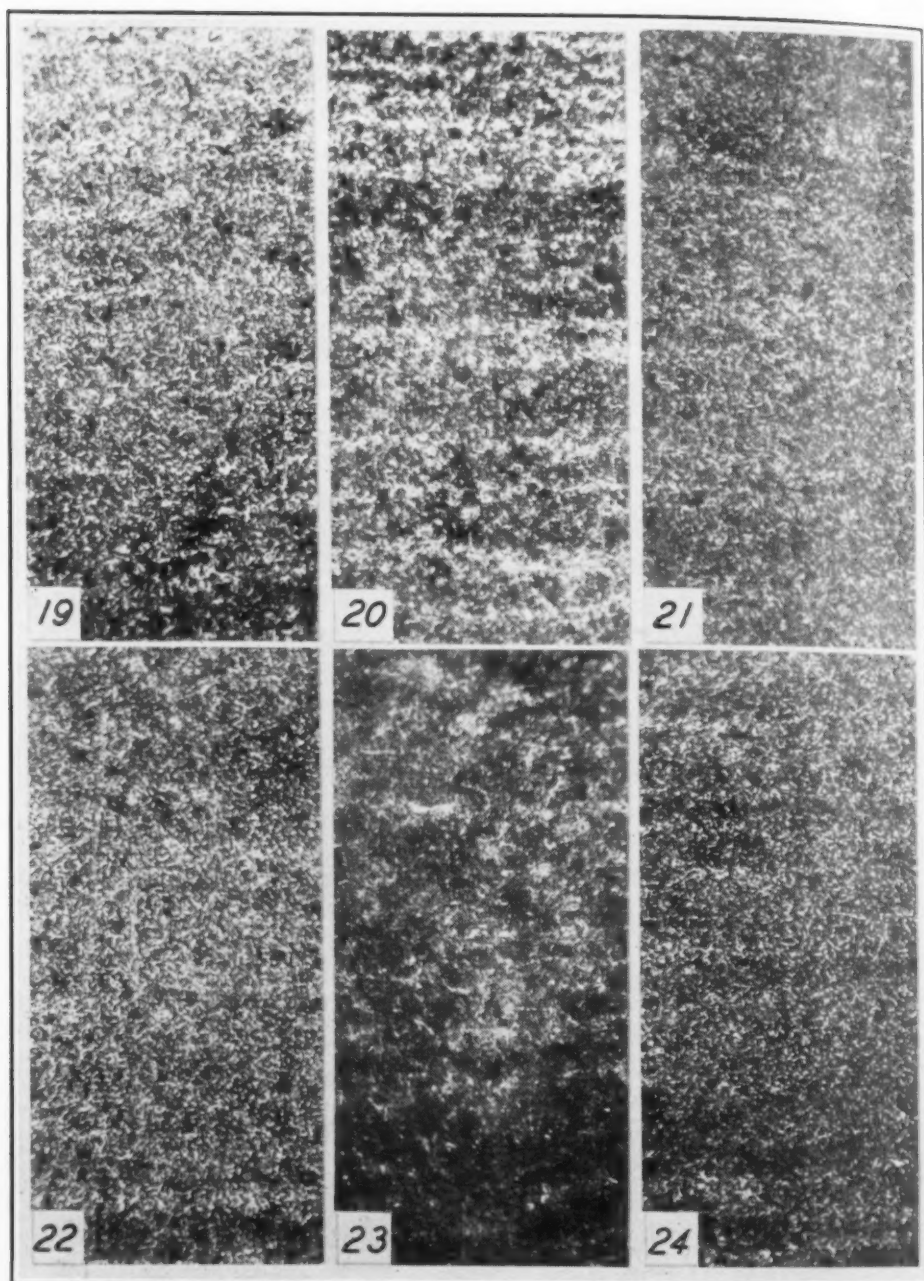
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Photomicrographs of S. A. E. 6140 Steel. Fig. 13—Bar 285. Heat Treatment No. 6. Structure Shows Considerable Spheroidizing with Structure not Quite so Dense as No. 286. Cutting Rating Fair (70 Per Cent). Fig. 14—Bar 286. Heat Treatment No. 6. Structure Shows Considerable Spheroidizing but Rather Dense Structure. Cutting Rating Fair (70 Per Cent). Fig. 15—Bar 287. Heat Treatment No. 6. Structure Very Much the Same as No. 285. Cutting Rating Fair (70 Per Cent). Fig. 16—Bar 272. Heat Treatment No. 7. Structure Shows Very Little Spheroidizing with the Banded Effect from Cold Drawing Very Decided. Cutting Rating Fair (70 Per Cent). Fig. 17—Bar 273. Heat Treatment No. 7. Structure Shows Considerable Spheroidizing. Cutting Rating Fair to Good (80 Per Cent). Fig. 18—Bar 274. Heat Treatment No. 7. Structure Very Much Like 272 with no Spheroidizing. Only More Coarse-Grained than 272. Cutting Rating Poor (50 Per Cent). All Photomicrographs $\times 100$.



Photomicrographs of S. A. E. 6140 Steel. Fig. 19—Bar 277. Heat Treatment No. 8. Shows Spheroidized Structure Quite Well Developed. Cutting Rating Fair to Good or Perhaps Good (85 Per Cent). Fig. 20—Bar 278. Heat Treatment No. 8. Structure Partially Spheroidized with Banded Structure of Drawing in Evidence. Cutting Rating Fair (70 Per Cent). Fig. 21—Bar 280. Heat Treatment No. 8. Structure Shows Considerable Spheroidizing, Although Rather Dense. Cutting Rating Fair (70 Per Cent). Fig. 22—Bar 275. Heat Treatment No. 9. Structure Shows Excellent Spheroidizing. Cutting Rating Good (90 Per Cent). Fig. 23—Bar 276. Heat Treatment No. 9. Shows an Annealed Structure with Practically no Divorcement of Pearlite into Ferrite and Cementite. Cutting Rating Very Poor (40 Per Cent). Fig. 24—Bar 279. Heat Treatment No. 9. Structure is Somewhat Granular or Spheroidized, but is not Sufficiently Open. Cutting Rating Poor (40 Per Cent). All Photomicrographs $\times 100$.

The drill press on which the torque and thrust values were determined was a short belt-driven Colburn No. 2 manufacturing type drill with a 5-horsepower motor mounted on the back of the column. On the table was mounted a specially designed dynamometer of the hydraulic type which would permit the torque and thrust to be registered automatically on a nearby Bristol recording gage. The torque values were also registered on a mercury column gage for check purposes, the scale of which was larger than that permitted on the Bristol gage chart.

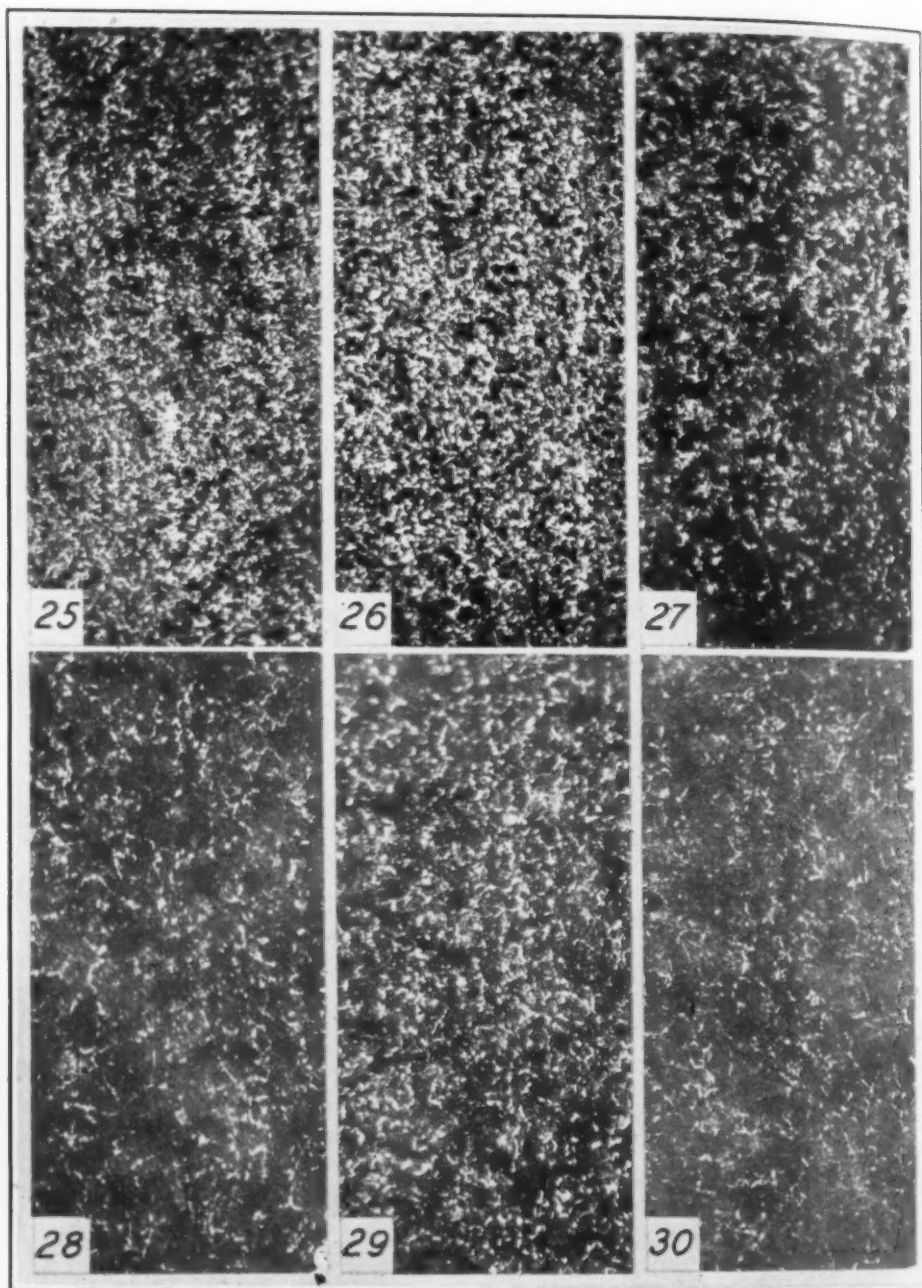
The drill penetration for these experiments is expressed in minutes and is the time required for a $\frac{1}{4}$ -inch standard high speed steel twist drill, having a helix angle of 30 degrees, a clearance angle of 4 degrees 42 minutes, to penetrate the material $\frac{1}{4}$ inch. The drill was rotated at a speed of 504 revolutions per minute under a dead load, including the weight of the spindle and drill, of 93.6 pounds. A special drill press for this purpose was used. The $\frac{1}{4}$ -inch depth of penetration was measured by using two beam type indicators which were attached to a Vernier surface height gage, so that their points were exactly $\frac{1}{4}$ inch apart vertically. A stop watch was started when the first indicator read zero and stopped when the second indicator read zero. The lower edge of the drill sleeve was ground flat and smooth and served as a reference surface.

All penetration tests were run with one drill grinding. All materials were tested in turn once, and then tested in the same order the second and third times without regrinding the drill to note the influence of the dulling of the drill. It was desirable to make all tests with one drill grinding, as it was found almost impossible, in preliminary tests, to grind a small drill twice alike, even though a machine grinder was used. The dulling of the drill during the three sets of test was thought to be negligible, as the average of the three, or in some cases more, tests did not differ from the one most divergent by more than three per cent in any case.

Brinell hardness numbers were also obtained for each material, in which the 3000-kilogram load was used with the 10-millimeter ball.

EXPERIMENTAL DATA AND DISCUSSION

The physical properties of all bars as indicated by the several



Photomicrographs of S. A. E. 6140 Steel. Fig. 25—Bar 352. Heat Treatment No. 10. Structure Shows Considerable Spheroidizing, with Some Evidence of Banded Structure. Fig. 26—Bar 353. Heat Treatment No. 10. Structure Same as 352. Fig. 27—Bar 364. Heat Treatment No. 10. Structure Shows Evidence of a Full Anneal, but not Much Spheroidizing. Cutting Rating Fair to Good (80 Per Cent). Fig. 28—Bar 427. Heat Treatment No. 11. Structure Shows an Anneal, but Practically no Spheroidizing. Cutting Rating Poor (40 Per Cent). Fig. 29—Bar No. 428. Heat Treatment No. 11. Structure Shows an Annealed Condition, but it is not Spheroidized. Cutting Rating Poor to Fair (50 Per Cent). Fig. 30—Bar 429. Heat Treatment No. 11. Structure About Same as No. 427. Cutting Rating Poor (40 Per Cent). All Photomicrographs $\times 100$.

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Fig. 31—Photomicrograph of S. A. E. 6140 Steel. Bar 430. Heat Treatment No. 11. Structure Shows Considerable Spheroidizing, Although it is not Complete. Cutting Rating Fair to Good (80 Per Cent). $\times 100$.

tests are tabulated opposite each bar number in Table III. The diameter of the test bar is also indicated, as it was thought this might possibly have some influence on the experimental data.

The physical properties, consisting of Brinell number, drill penetration, drill torque, drill thrust, and cutting rating, as listed in Table III, are plotted over the bar numbers in the order given in Fig. 32. The average of all the physical properties of all bars for each heat treatment are plotted over the heat treatment number in Fig. 33. In this case, the steels of lot A, having the higher carbon content as listed in Table I, consisting of alternate bars No. 237, 246, 251, and 255, are shown plotted over their respective heat treatments first, after which are shown the lower carbon steels, Nos. 238, 248, 252, and 256, over their heat treatments. It is to be noted that bars 237 and 238 have the same treatment, as is the case with bars 246 and 248, etc. For the lot B steels, the physical properties of all bars for that heat treatment are averaged.

In Fig. 34 are plotted the same values as shown in Fig. 33,

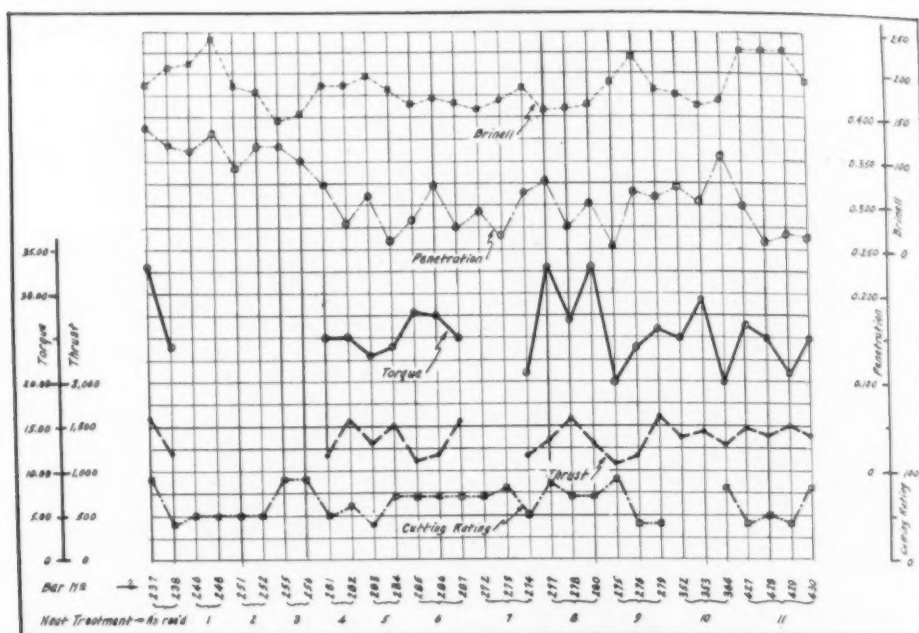


Fig. 32—Curves Showing the Physical Properties of S. A. E. 6140 Steels, Lots A and B, as Listed in Table III. These are Plotted Over the Bar Numbers. In All Curves Penetration is Measured in Minutes per $\frac{1}{4}$ Inch Depth.

except that the heat treatments have been arranged in decreasing order of Brinell numbers for the two steels of lot A and for those of lot B. In Fig. 35 are plotted over the heat treatment numbers, arranged in decreasing order of Brinell numbers, the average of the two best values of each property for each heat treatment. In other words, the most divergent value of each test for a given heat treatment was discarded.

DISCUSSION OF RESULTS

In Fig. 32 where the physical properties for each steel as listed in Table III are plotted over the bar number and the bar numbers grouped for the heat treatment number, it is seen that in many instances the physical properties for a given heat treatment number vary for the different steels. This might be expected in the first five heat treatments, that is, 'as received' to '4', inclusive, because the bars grouped together for a given heat treatment vary slightly in chemical composition. This is not so true, however, for the heat treatments 5 to 11, inclusive. The steels of lot A average about four and one half points higher in carbon content

Table III
Physical Properties of the
Alloy Steels, S.A.E. 6140

Material No. Dia.	Heat Treatment*	Brinell No.	3/4 Inch Drill Torque Ft. Lbs.	Drill Thrust Lbs.	Minutes for 1/4 inch drill to penetrate 1/4 inch	Cutting Rating Per Cent
Lot "A"						
237 1 7/8	As Received	187	33	1580	0.3884	90
238 1 7/8	As Received	206	24	1200	0.3683	40
246 1 7/8	1	212	No Material		0.3616	50
248 1 7/8	1	241	No Material		0.3818	50
251 1 7/8	2	186	No Material		0.3433	50
252 1 7/8	2	179	No Material		0.3667	50
255 1 7/8	3	146	No Material		0.3667	90
256 1 7/8	3	153	No Material		0.350	90
Lot "B"						
281 1 1/4	4	186	25	1175	0.3235	50
282 1 7/16	4	186	25	1550	0.280	60
283 1 1/4	5	197	23	1320	0.310	40
284 1 7/16	5	181	24	1500	0.260	70
285 1 1/8	6	165	28	1120	0.283	70
286 1 1/4	6	172	27.5	1180	0.323	70
287 1 7/16	6	166	25	1550	0.275	70
272 7/8	7	159	..	....	0.2935	70
273 3/4	7	169	..	....	0.266	80
274 1 5/16	7	184	21	1175	0.315	50
277 1 1/8	8	158	33	1350	0.328	85
278 1 7/16	8	160	27	1580	0.2775	70
280 1 1/8	8	165	33	1320	0.3025	70
275 1 1/8	9	190	20	1090	0.2535	90
276 1 1/4	9	220	24	1175	0.3166	40
279 1 7/16	9	182	26	1600	0.310	40
352 1 1/16	10	176	25	1380	0.3206	..
353 1 1/16	10	163	29.5	1450	0.305	..
364 1 3/8	10	170	20	1300	0.357	80
427 1	11	228	26.5	1475	0.300	40
428 1	11	228	25	1400	0.260	50
429 15/16	11	228	21	1500	0.269	40
430 15/16	11	192	25	1400	0.265	80

*See Table II.

than those of lot B, and it might be expected that the steels of lot A would machine with more difficulty. This is indicated in Fig. 33, in that the Brinell numbers of lot A, with the exception of those for heat treatment 3, bars 255 and 256, are higher than those for lot B, heat treatments 9 and 11 excepted.

The drill penetrations of the lot A steels, Fig. 32 are shown consistently higher than for those of lot B. This comparison is not possible with the thrust and torque, in that only bars 237 and 238 of lot A were available for torque and thrust tests.

There seems to be no evidence of prevailing influence of the heat treatment on the Brinell, penetration, thrust, or torque values. The test data differ at times within a single heat treatment more than between two steels of different treatments.

The cutting rating values also vary less in some instances be-

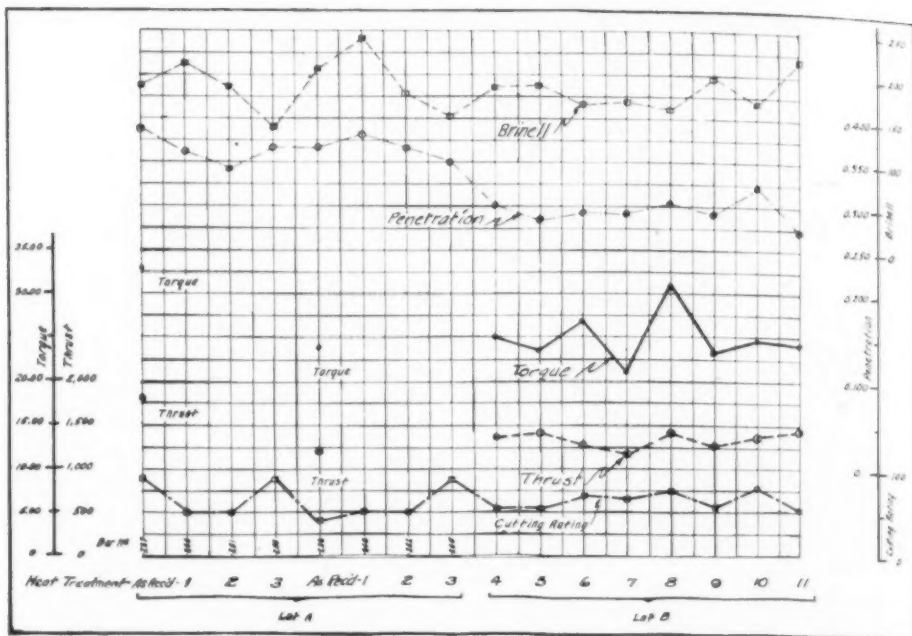


Fig. 33—Curves Showing the Average of All the Physical Properties of All Bars for Each Heat Treatment Plotted Over the Heat Treatment Number S. A. E. 6140 Steels, Lots A and B.

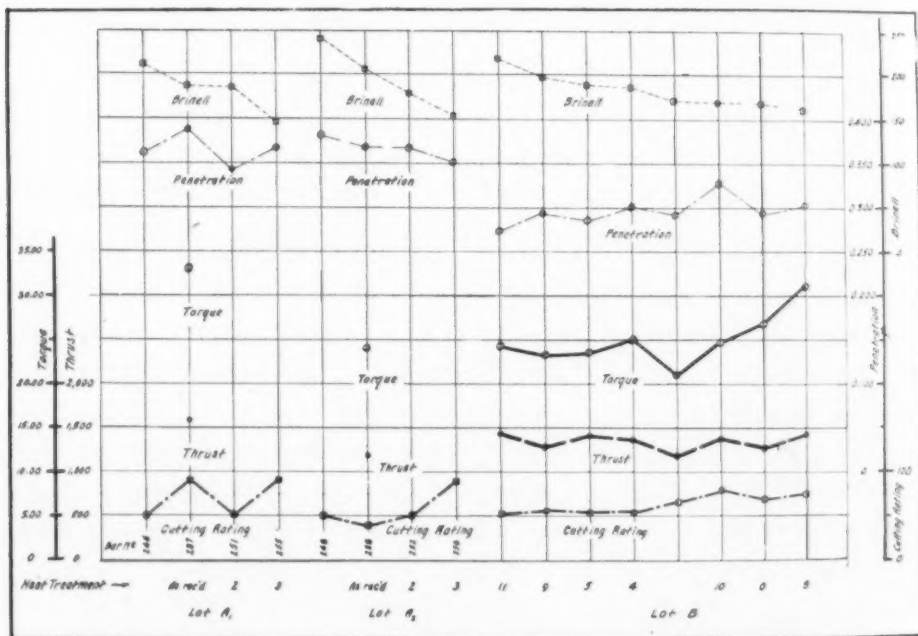


Fig. 34—Curves Showing the Average of All the Physical Properties of All Bars for Each Heat Treatment Plotted Over the Heat Treatment Number, But Arranged in Decreasing Order of Brinell Number for Each Group. S. A. E. 6140 Steels, Lots A and B. Note: Values Plotted for Lot B are Averages for All Bars of Each Heat Treatment.

tween steels of different heat treatments than between those of the same treatment. Such examples are seen for heat treatments 'as received', 5, 7, 9, and 11. The cutting rating curve, however, does appear to vary inversely with the Brinell number curve, as when the Brinell number is high for a steel, the cutting rating value is low. This seems generally true for isolated steels or steels of the same treatment, such as, for example, No. 11.

When the cutting rating value for a steel is compared with the amount of spheroidized structure of that steel as determined from the photomicrograph, it is seen that a close relation exists between the two. That is, the greater the spheroidizing, the higher the cutting rating. Steels with practically no spheroidizing are Nos. 238 Fig. 2, 252 Fig. 6, 274 Fig. 18, 276 Fig. 23, 364 Fig. 27, 427 Fig. 28, 428 Fig. 29, 429 Fig. 30, all of which, with the exception of 364, have low cutting ratings. On the other hand, those steels showing a fair to good spheroidized structure, such as 237 Fig. 1, 255 Fig. 7, 256 Fig. 8, 273 Fig. 17, 277 Fig. 19, 275 Fig. 22, and 430 Fig. 31, show cutting ratings of high value.

In Fig. 33 are shown the averages of each test for all steels for each heat treatment, plotted over the heat treatments as abscissas. The actual experimental values from the tests are plotted over each material for lot A, because only one steel of each analysis was available for each heat treatment. The values plotted over the treatments for the lot B steels are averages. From these curves, it is seen that the penetration curve varies almost directly with the Brinell curve, steel 255 excepted.

The cutting rating curve appears to be the inverse of the Brinell hardness number curve, as where the Brinell number is low, the cutting rating is high and vice versa.

The torque and thrust curves do not seem to throw much light on the question of machinability as influenced by the various treatments. The low point for heat treat 7 is based on one steel No. 274, the only one available for torque and thrust tests because of the small size of the piece.

In Fig. 34, the values shown plotted in Fig. 33 are replotted over the heat treatment numbers, but are arranged in decreasing order of the Brinell number for each group.

Lot A1, consisting of bars 237, 246, 251, and 255 of Table I, which have a carbon content of 0.48 per cent, show that the penetra-

tion and cutting rating curves are similar. Both the penetration and cutting rating are low for bar 251, which, as illustrated in Fig. 5, shows that the material has had a previous treatment, in that a slight spheroidizing is evident.

Steel 246 has a low cutting rating, but slightly higher penetration, and as shown in Fig. 3, the structure has only a slight

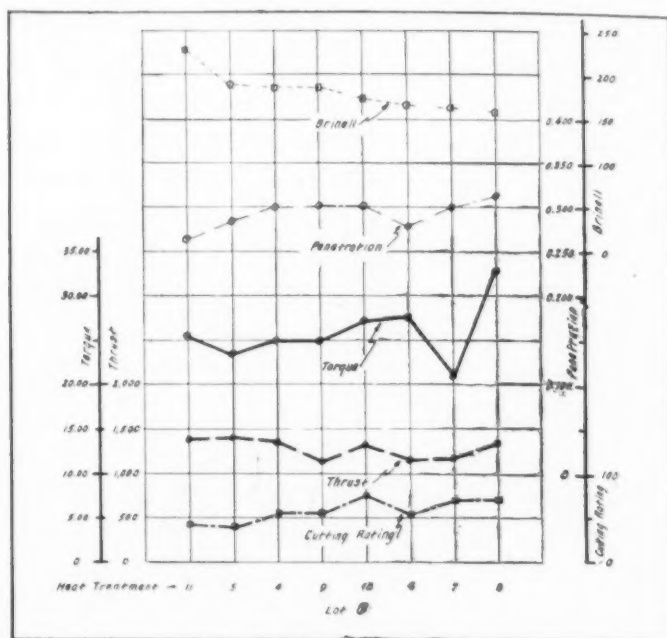


Fig. 35—Curves Showing Physical Properties of Lot B Steels Plotted Over the Heat Treatment Numbers Arranged in Decreasing Order of Brinell Numbers. Note: Values Plotted are Averages of the Two Best Values of Each Heat Treatment.

tendency to spheroidize. Steel 255 has a high chip rating and relatively high penetration, and as shown in Fig. 7, the structure shows a semi-spheroidized condition. Steel 237 shows a condition similar to that of 255, that is, for a semi-spheroidized condition, Fig. 1, the cutting rating and penetration are high.

The relation between the spheroidized condition and the cutting rating and penetration are not so favorable, however, for the Lot A₂ steels, as indicated in Fig. 34. The penetration is highest for steel 248 which has a low cutting rating and is lowest for the group for steel 256 which has the highest cutting rating. Steel 248 has a slight spheroidized condition, while steel 256 has a semi-spheroidized structure.

For lot B, Fig. 34, the spheroidized structure is best for heat treat numbers 10, 6, and 8 in the order given. The chip rating is highest for these treatments. The penetration for treatment 10 is highest and is relatively high for 6 and 8. The Brinell values for these treatments are the lowest of the group.

The average of the two best test values of each heat treatment of the lot B steels are plotted over the heat treat numbers in Fig. 35. Again, the heat treatment numbers are arranged in decreasing order of Brinell numbers. It appears that the cutting rating increases with a reduction in Brinell number. This same relation seems to hold in Fig. 35 as well as Fig. 34 for the penetration and torque curves. The thrust curve seems to be of little value in determining the machinability quality.

CONCLUSIONS

It appears from the above results that a pure annealing does not give the best machining qualities. It appears that where the greatest divorcement of pearlite into its constituents, ferrite and cementite, that is when the steel is spheroidized, the machinability, as indicated by the chip rating and drill penetration, is highest. The drill torque, also, seems to increase as the machining qualities of the material are improved, while the drill thrust apparently has no relation to the machining qualities.

DISCUSSION

Written Discussion: By A. L. Davis, Scovill Mfg. Co., Waterbury, Conn.

This paper represents a large amount of careful work in the execution of tests, and in the presentation of results. An adequate discussion is impossible without personal examination of the specimens under the microscope, and without having had the opportunity to note the condition of the lathe tool at the end of each test.

The conclusion of the authors that "drill torque increases as the machining quality improves" is, of course, intended as tentative only. The average torque corresponding to the five specimens showing the highest cutting-rating (average 85) is 26, as against an average torque corresponding to the 6 specimens showing the lowest cutting rating (average 40) of 24. This difference between 24 and 26 for torque is not great when we consider the variation between individual tests. Therefore I feel that this point should be held open till further evidence is available.

Study of the tests shows that the cutting rating of the specimens is roughly proportional to the Brinell hardness, excepting for five notable exceptions. These exceptions are bars 252, shown by micrograph Fig. 6, and

279, shown by micrograph Fig. 24, which have a cutting rating of 50 to 40 respectively, which is a lower rating than would be judged on the basis of Brinell hardness; and bars 237, 275, and 430 (illustrated by micrographs Figs. 1, 22, and 31) all of which have a much higher cutting rating than would be judged on a basis of their Brinell hardness. The problem is to explain these discrepancies. The tests for these five bars are shown in the following table.

Micrograph No.	Bar No.	Per Cent Carbon	Heat Treatment	Brinell	Cutting rating, Per Cent	Microstructure
24	279	0.43	Cold drawn	182	40	Somewhat granular or spheroidized, but close.
22	275	0.42	Cold drawn	190	90	Fully spheroidized.
6	252	0.47	# 2 (Anneal)	179	50	Pearlite.
1	237	0.48	As received (Anneal)	187	90	Semi-spheroidized.
31	430	0.41	Cold drawn	192	80	Considerably spheroidized.

There is a lack of concordance clearly seen between bars 275 and 279, and between 237 and 252. This discrepancy between Brinell hardness and cutting rating is partially explained by the microstructure reported, but not as fully explained as would be desirable. If a suggestion were to be made it would be that a more intensive micro-examination be made of these particular bars with a view to bringing out in an exhaustive way the structural difference as between each of the two pairs. It is possible that the original micrographs and other data on record do cover this matter fully, but the published photomicrographs in the preprint of the article do not show a sufficiently marked difference, for example, between figures numbers 22 and 24 to explain a difference in cutting rating of 90 as against 40.

Nothing in the above remarks is to be construed as a lack of appreciation for the achievements set forth in the paper of Messrs. Boston and Landis. The subject is admittedly a difficult one, as will be appreciated by anyone who has had practical experience in machinability tests. It must be a matter of satisfaction to the authors to have made the progress they report.

Written Discussion: By Dr. Max Kurrein, Technische Hochschule, Charlottenburg.

Having read the report with great interest I could not quite understand the remark on page 459, line 12 (from the bottom), "make all tests with one drill grinding . . ."

My researches showed a distinct difference within the diagrams of the first holes drilled with a newly sharpened drill. Continued drilling without regrinding the drills produces similar diagrams until the first signs of dulling appear in the diagram.

I could not find great difficulties in grinding drills so far alike, that they did not show differences in the lines of the drill point measuring apparatus nor in the torque and thrust diagrams.

Oral Discussion

A. H. D'ARCAMBAL: Mr. Chairman, we hear a great deal about the various machining qualities of the different types of alloy steels. I know that Professor Boston has tested several different types of alloy steels, such as chrome-vanadium, chrome-nickel, 3½ per cent nickel, chrome-molybdenum, etc., and I was wondering if he has anything to offer on the relative machining qualities of the different alloy steels having about the same Brinell hardness.

H. J. FISCHBECK: The photomicrographs shown in this paper are of 100 diameters magnification. I would like to know if the authors have examined their specimens at higher magnifications, 1,000 diameters for instance. From tests made along similar lines we could tell more about machinability at high magnifications than at 100 diameters.

H. J. FRENCH: I would like to ask the authors to explain, just why they lumped a very definite determination, namely, tool life, with a determination which was obviously dependent upon the viewpoint of the operator, to give the so-called "cutting rating," instead of reporting separately the tool life and the character of the machined surface. Possibly the actual values of tool life, when plotted against the hardness and referred to the microstructure, might explain some of the discrepancies which Prof. Boston mentioned in his presentation.

Authors' Closure

In regard to Mr. d'Arcambal's question as to the machinability of alloy steels of the same Brinell hardness, I believe the best information available is that given by Messrs. French and Digges in their paper "Rough Turning with Particular Reference to the Steel Cut" Trans. A.S.M.E., Vol. 48, 1926, pp. 533-607. Fig. 8, page 555, shows the Taylor speed in feet per minute for several different steels on an equal tensile strength basis. From this the Taylor speed for the different metals may be read for any tensile strength.

I have a great deal of data showing relative values for a wide range of carbon and alloy steels for several different tests. The tests consisted of measuring the energy absorbed by a single tooth milling cutter of specific size, shape, and for a definite chip; the force on a planer tool of a given size, shape, and for a definite chip; the torque and thrust of a ¾ inch diameter drill rotating at 153 revolutions per minute with a feed of 0.012 inches; and the penetration of the ¼-inch diameter drill per 100 revolutions per minute under a given load. The materials, however, are not on a basis of equal Brinell numbers.

Mr. French very properly raised the question as to just why the cutting rating is based on two independent factors, such as tool life and finish, considered jointly. The tool life is a definite determination, but to classify

or grade the finish, obviously requires considerable ingenuity on the part of the observer. This part of the work was done by Mr. Landis at his laboratory in Chicago before the other mechanical tests were undertaken. Mr. Landis reports, however, "that although the amount of material cut and the condition of the surface appear to be two different characteristics, commercial machinability rating must depend upon both and that is what I had in mind when I made these determinations. As a matter of fact, I personally believe that with the tooling, etc. being comparable, the cutting rating based on tool life, finish, or amount of material removed will give the same comparative rating. The chip shape is a factor which I have used in rating screw stock, but this was not used for the tests included in this paper."

We are now working on a project at the University of Michigan to determine for various alloy steels for gears the correct heat treatment to give a satisfactory finish. This does not involve tool life in any way. Obviously, the first question to consider is a yardstick to measure finish on some scientific basis.

Dr. Ing. Kurrein raises the question of drill grinding for these tests. It is not clear to me whether he is referring to the penetration drill or the torque and thrust drill, so I shall comment on both. The $\frac{3}{4}$ -inch twist drill used for determining torque and thrust was very carefully ground on the Blau (Austrian) drill grinder. The machine setting was recorded and all measurements of the drill taken, so that if necessary, the grinding could be duplicated in every respect. The drill was carefully measured to make sure that the chisel point or dead center was on center and that the lips were of the same length and location with respect to the axis, so that chips of equal depth would be taken by each. The tool was honed so that the burrs were removed before drilling was started. From a large number of tests for the one grinding, no difference in cutting action could be observed between the newly-ground-honed drill and the condition after use. The one grinding and honing lasted throughout the tests given in this paper.

As for grinding the $\frac{1}{4}$ -inch diameter drill used for the penetration tests, we again used a small Blau drill grinder and kept on grinding until by actual tests we observed that the drill was cutting uniformly on both edges. A thickness of chip for tests of this nature of about 0.001 inch is common, so that it was necessary that the grinding provide a point as near a geometrically desired one as possible. This grinding lasted throughout the tests recorded here. It was found, however, that it was practically impossible to regrind this drill and secure results which would conform with those of a previous grinding. In work involving this drill, on other groups of metals, not yet published, the drill was reground but in each case one particular piece of metal was kept as a reference piece to check the grinding so as to get uniform results as nearly as possible.

The authors had no intention of setting up a law, as indicated by the conclusions of this paper as referred to by Mr. Davis in his written communication. The tests were made on materials, the bars of which had been collected over a period of time, and the heat treatments had already

been given them before the mechanical tests were started. Just how much the difference in size of the bars or the different conditions under which each was manufactured, influences the results obtained is difficult to say.

Since Mr. Fishbeck of the Pratt and Whitney Co. raises the question as to the examination of the specimens at magnifications of approximately 1,000 times, A. L. Davis of the Scovill Mfg. Co. has kindly consented to subject the specimens to this test. Mr. Davis was supplied with the original photomicrographs and also with the polished specimens of all steels. Mr. Davis's report on his investigation follows:

"I have been studying over the figures given in the paper by you and Mr. Landis, and have had most of the specimens repolished and etched, both with nitric acid and pieric acid. The pieric acid proved to be less desirable than the nitric acid for the specimens. Walter N. Van Tassel has assisted me in studying the specimens under the microscope, at about 700 diameters and also 2500 diameters.

"We have not found anything which throws much light on the problem. Both Mr. Van Tassel and I feel that the micrographic description of the specimens given in your paper are surprisingly accurate. There are some minor points of which individuals will always differ in their opinion concerning such specimens.

"We agree in regarding specimens from bar No. 275 as showing the nearest approach to perfect spheroidization. It is rather interesting that this specimen is the only one for which all of your machining tests are in accord. You give it a cutting rating of 90 per cent. It also required the shortest period of time to accomplish $\frac{1}{4}$ -inch penetration of drill under constant load, and both the torque and thrust of the $\frac{3}{4}$ -inch drill are lower for this specimen than for any other. It is significant that the Brinell hardness (190) of this specimen is not by any means the lowest Brinell hardness reported.

"It is interesting to compare with the above specimen that from bar No. 237, having a Brinell hardness of 187, and accorded a cutting rating of 90 per cent, the same as bar No. 275. This bar No. 237 with almost equal Brinell hardness, and also an identical cutting rating, required more than 50 per cent longer time for the $\frac{1}{4}$ -inch drill under constant load to achieve $\frac{1}{4}$ -inch penetration. It also required 50 per cent greater thrust and 65 per cent greater torque to drive the $\frac{3}{4}$ -inch drill at the same speed and cut. The micrographic description for bar No. 237 is given as semi-spheroidized.

"There is another bar which presents an anomaly. This is No. 279 of 182 Brinell hardness and only 40 per cent cutting rating. The micrographic description is 'somewhat spheroidized, but very close grain.'

"This entire problem impresses Mr. Van Tassel and myself as one of great difficulty. It is our feeling that it is only going to be solved by very thorough and painstaking work in correlating heat treatment with resulting microstructure and also with Brinell hardness. Whether this particular analysis of steel will be the best on which to carry out such a research

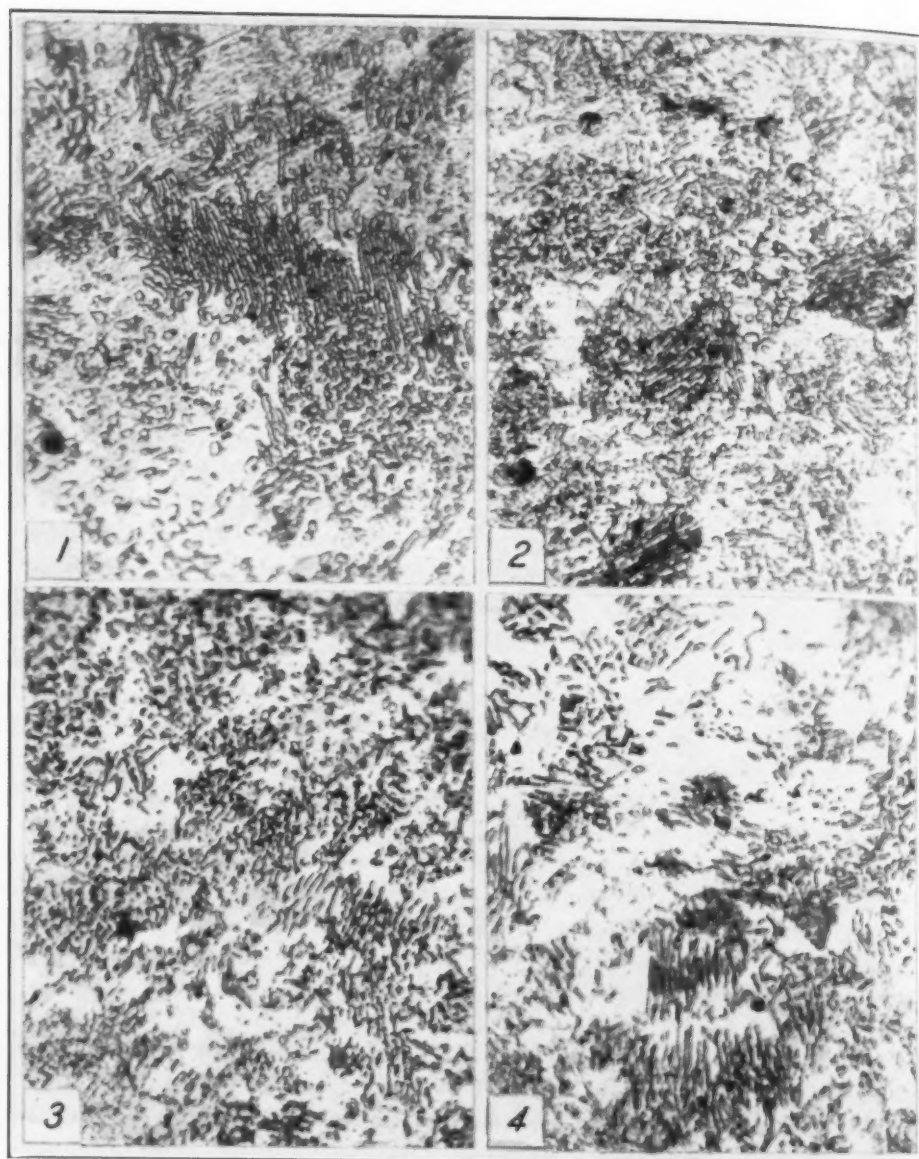


Fig. 1—Photomicrograph of Specimen No. 237, Cutting Rating 90. Fig. 2—Photomicrograph of Specimen No. 255, Cutting Rating 90. Fig. 3—Photomicrograph of Specimen No. 275, Cutting Rating 90. Fig. 4—Photomicrograph of Specimen No. 279, Cutting Rating 40. All Specimens Etched in Nital. All Magnifications $\times 1000$.

is perhaps a question. Just as the Bureau of Standards is slowly building up a mass of accurate information as to quenching fluids and their rate of cooling in quenching, together with the physical properties of steels thus treated, so we conceive it will be necessary to do likewise in establishing the connection between accurately controlled heatings and quenchings, with the resulting microstructures and Brinell hardness. When this has been done and a condition reached where it is possible to reproduce with reason-

able accuracy a given structure and a given Brinell hardness, then on such standardized material we feel that your testing machines will be able to record results which harmonize between different methods of testing, and which will reveal such relationships as we are looking for."

Micrographs at $\times 1000$ representing bars 237, 255, and 275, all of which received a cutting rating of 90 per cent, and also bar 279 which had a cutting rating of only 40 per cent, are shown in Figs. 1 to 4, inclusive.

Mr. Davis reports that in making the micrographs, a portion of the section was photographed, which showed the most pronounced lamella of the pearlite, that is, the worst looking portion of the section so far as spheroidizing is concerned. Mr. Davis further continues as follows:

"It is apparent that complete, or perfect, spheroidization was not obtained in any case. It is also, I think, apparent from the micrographs that the three bars which have the cutting rating of 90 are better spheroidized than is the bar with the cutting rating of 40, but there is not as much difference in the microstructure as one would have expected, to account for the difference in cutting rating.

"Doubtless you have seen E. G. Herbert's articles on machinability in the English weekly 'Engineering', the concluding issue being that of Dec. 28, 1928. Mr. Herbert has done a fine piece of work, which strikes me will throw more light upon the machinability of metals than any other single investigation thus far made. Mr. Herbert finds that it is not the initial hardness of the metal being cut, nor even its work hardening capacity which determines its machinability, but rather the property of the metal in virtue of which it builds up on the nose of the cutting tool a permanent, or semi-permanent, tip having the optimum angle for free cutting.

"Looked at in the light of Mr. Herbert's investigation, we can understand how it can be possible for a relatively slight difference in structure to make a large difference in the angular form built out of the material in question upon the nose of the cutting tool. Thus a structure such as that of bar No. 279 might fail to build up a tip of the proper angle on the nose of the tool, whilst on the other hand, steel of identical analysis and practically identical Brinell hardness, but with different microstructure such as that of specimen No. 275 would build a tip having a favorable angle for free cutting."

The authors wish to express their appreciation to Mr. Davis for making his painstaking analysis of the specimens, and to the others who have contributed in making this paper of interest and benefit.

THE APPLICATION OF SCIENCE TO THE STEEL INDUSTRY

BY DR. W. H. HATFIELD

Abstract

The far-reaching influence of the work of Edward De Mille Campbell in the development of the metallurgy of iron and steel is discussed in this paper. It is pointed out that metallurgical investigation has progressed far but there is much more to be done. The author points to present practices which offer great fields for improvement and increased efficiencies.

The fields of pure and applied science are shown to be very closely connected and that those who are particularly fitted to carry on work in the basic sciences should be given every opportunity, as it is upon the fundamental knowledge that the application of science to industry is dependent. The English practice in various steel making processes is described. Oxygen determination is dealt with at some length. Various methods are discussed and the defects of each pointed out. The common methods of temperature measurements of liquid steel are described and the precautions necessary for accurate results are considered.

INTRODUCTION

TO BE invited by American scientists and technologists to give the 1928 Lecture in memory of Professor Edward de Mille Campbell, is indeed an honor deeply felt by the author. The period which Campbell's work covered was a constructive one of the first magnitude in the development of the metallurgy of iron and steel. The work of the investigators of those years might be compared with trekking into unknown territory. We, today, are largely engaged in following up and intensely studying the ground they first turned over; in some cases using the same methods, in others, having the advantage of new instruments and even new

This paper is the first section of the third Edward De Mille Campbell Memorial Lecture presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928, which is being published in six sections in consecutive issues of TRANSACTIONS. The author, Dr. W. H. Hatfield, is director of the Brown-Firth Research Laboratories, Sheffield, England.

lines of attack. Their achievements, however, put ferrous metallurgy upon its feet. In that period, the imagination and the constructive mental ability of Professor Campbell came into play, and his effect upon contemporary work was due not only to his contributions to knowledge, but also to the impetus given to the experimental work of others by the theoretical views which he invariably put forward concerning the work upon which he had been engaged. The matter and manner of his writings always engaged the most serious attention upon our side of the Atlantic.

The versatility of his genius is displayed in the titles of his contributions covering the period 1885 to 1926; his indomitable pluck, by the fact that from the age of 28 his work was continued under the disability of blindness resulting from his tragic accident while investigating the constitution of steel.

His early work, and it was invaluable, contributed to placing the analysis of steel upon a practical basis. His work upon the constitution of steel, with particular reference to the condition in which the carbon occurred, extended over a long period, and was interspersed with efforts in several directions, notably on the diffusion of sulphur, the heat of formation of carbides and silicides, dry air blast as applied to blast furnaces; whilst his later period was given up to such diverse problems as the effect of hydrogen, the hardness of steel, the physical properties of steel, the constitution of chromium steel, and he lived to take a great interest in the newest development in our subject, viz., the X-ray method of attack. His field was very large, and his genius invariably illuminated each subject that he touched. He was too earnest an investigator and too daring a theorist to expect all of his deductions to be confirmed as knowledge unfolded itself, but of his niche in the Valhalla of our sciences, there is no doubt.

How can I best speak to you in commemoration of his efforts? After very serious consideration I came to the conclusion that, in view of Professor Campbell's wide field, I was encouraged to make my subject "The Application of Science in the Steel Industry." I do so with less diffidence, since I come from afar, and it may be useful to you to have a view of matters as they exist today from a European standpoint.

Metallurgical investigation has progressed far, but as one actively engaged in the field of research and in the application of

science to the industry, I am overwhelmed when I realize how much there is that we still do not know; when I realize how many of the simplest expedients in the industry are archaic, and how relatively backward is science in supplying the knowledge of natural law necessary for advancement; with many of the commonly accepted and so-called "facts" which I really believe are not facts at all.

The essential functions of scientifically trained men engaged within an industry consist in improving either the processes or the products of that industry by the application of new knowledge available either (a) as the result of independent research, pursued with or without special reference to the industry, or (b) rendered available by a patient research within the industry. The financial resources necessary for the work coming under category (b) are now being reasonably provided in some industries, and with gratifying results in regards to technical progress yielding increased amenities and convenience in one direction or another. With regard to the increasing of knowledge under category (a), the position is hardly as satisfactory, since it involves the effort of many capable investigators over longer periods of time without any immediate prospect of financial return. Industrial enterprise, unless it is very broad minded and is sufficiently prosperous to "cast its bread upon the waters," is inclined to leave the extension of purely scientific knowledge to the enthusiasm of the relatively small band of scientific men whom nature has endowed with the spirit of enquiry, the intellect, and the natural aptitude so requisite for the work. I think that every modern State should study most intensively and then put into effect the best means it can devise for ensuring that such gifted men (and women) as may be born thereto are enabled to work in a suitable environment, and with adequate resources for experiment. It needs them all. This may seem rather a platitude, but the experience of the times clearly indicates that with so much accomplished in the industrial world on the efforts of substantially unassisted fundamental scientific progress, how much more may be accomplished by adequate encouragement and facilities. In America, Britain and elsewhere much is now being done, but not sufficient. No service to the State transcends in value that which can be rendered in increasing our knowledge of the laws and possi-

bilities of nature, and perhaps the time may come when this will be more generally realized. Next in value comes the service of the men who can apply such new knowledge to the good of the State. Indeed, those who can apply such knowledge successfully have, in addition to their adequate understanding of the matter with which they are dealing, frequently to extend still further the knowledge for its complete application. Thus comes the great difficulty of defining what might be considered in the one case, to be the work of the "pure" and, in the other, that of the "applied" scientist. I hope to show that even as regards our own mundane iron and steel industries, no line of demarcation can be drawn.

A man engaged in applying science to industry, has inevitably, on numerous occasions, to deplore his lack of opportunity and time, to follow up the threads of fundamental knowledge with a view to providing information which he considers essential to an adequate solution of his problem, but which is as yet lacking. These extensions of knowledge may be of such an order that their gradual achievement can only be hoped for, as a result of the collective work of the scientific world; on the other hand, the desired information might in certain cases surely be yielded as a result of immediate careful and patient work in "pure science." Of the former kind, is a more complete knowledge of the nature and the constitution of matter involving the nature of the atom, of cohesion, of "chemical" combination, of the nature of solution (particularly of so-called compounds); of the latter kind, the mastering of problems in physical chemistry, of the determination of physical constants under difficult conditions. Many other problems can, of course, be cited.

The problems engaging attention in the industry are generally those of introducing new, or modifying old processes, or introducing new, or improving old products; generally surmounting difficulties and eliminating defects. A very wide field of science is necessarily laid under contribution, and it surpasses the ability of the individual mind to be expert in each branch of science necessarily called into play in dealing with even any one particular industry. It thus follows that a modern research institution, such as the one the author has the pleasure of directing, is necessarily divided into a number of laboratories, chemical, physical, mechani-

cal, corrosion, metallographic, pyrometric, heat treatment, etc., each section having at its head a man particularly specializing upon his subject. Of the utmost importance is the free exchange of knowledge and ideas between the several sections, since although specialization is necessary, the general bearing of any work undertaken must never be lost to sight.

In surveying the steel industry, one is first struck by the present extravagant use of fuel, or energy, in the metallurgical and reheating processes. Iron and steel are certainly produced "cheaply" from our present point of view, but when one considers the present blast furnace plus refining furnace procedure, in which perforce abnormal fuel consumption is largely caused by the introduction of 3 to 4 per cent of carbon into the metal in the blast furnace and its subsequent elimination in the steel making process; surely it may be concluded that we shall receive a passing smile from posterity. The achievement of efficient direct reduction on a large scale in terms of energy consumed is a foregone conclusion, but its realization involves technical optimism, a long purse and a severe economic struggle. It is a big idea, and in America may be realized. The author has heard rumors of practical attempts over here of which he hopes to learn more during this visit.

Turning to current processes, the overall efficiency of the coke crucible steel making furnace as still used by some of the Sheffield steelmakers, is as low as 2.5 per cent, the open-hearth does not exceed 17.5 per cent, whilst the efficiency of the electric steel making furnaces is of the order of 10 per cent. This latter value is very low for our latest metallurgical success in this field, but is, of course, due to the present large margin of room for greater efficiency as regards the practical achievements of those responsible for power production. The devices which we now know as power producing units with 15 to 25 per cent efficiency must be necessarily only a passing phase, and it is noticeable that, in his desire for improvement, the electrical engineer is now asking for greater assistance from the metallurgist; calling upon him to modify and to improve the properties of his materials, with a view to securing greater efficiency by the more effective utilization of well-tried laws. The metallurgist welcomes the opportunity to help, and on this matter the author will have something to

say later. Nevertheless, great advances will, no doubt, be made by the physicist, who is able to soar above the limitations of the ordinary rut of practice. The author is led to wonder as to the possibilities of entirely new methods for rendering available the required energy for our processes. Electric fuel cells working under reversible conditions and other ideas as yet unborn giving 95 to 100 per cent efficiency¹ may, for the time being, be unrealizable dreams, but we may expect much from the physicist in fundamentally modifying our industrial efficiency in this respect. The efficiency of our reheating and treatment furnaces similarly present a field for immediate practical and far more distant and ultimately successful treatment.

The production of steels of improved mechanical and more useful physical properties, has proceeded apace during the last few decades, and the development in this field is by no means exhausted. The mastering of the details of technique necessary to give increased reliability can be said to have progressed concurrently with the development of the new steels. These aspects were never more thoroughly emphasized than by Lindbergh's flight from America to Europe, and when at the banquet given to Colonel Lindbergh at the Savoy Hotel in London by our British scientific and technical people, the author listened to the Colonel's description of the trip, how for hundreds of miles in a dense fog he held on in justifiable faith in his machine, it was clear that, metaphorically speaking, hats were taken off not only to his great skill and pluck, but also to contemporary aero engineering and ferrous metallurgy. British metallurgy may reasonably claim its mead of praise in connection with the recent achievement of the Schneider cup.

Can we hope further for fundamental improvements in the properties of metals? Surely the hope is encouraged by isolated indications such as the work of the physicist Griffiths² on quartz. Physical considerations led him to suppose that the intrinsic strength of solids was not achieved in practice owing to extraneous effects. This was demonstrated by experimentally raising the ordinary value of about 25,000 pounds per square inch for a glass, to a value of nearly 500,000 pounds per square inch. By

¹U. R. Evans, Glasgow Technical College Metallurgical Club Journal, 1926.

²Mr. Griffiths, *Philosophical Transactions*, 1920, 221A, p. 163.

his process of preparation and the elimination of "flaws" this remarkable result was achieved. Is it too much to suppose that steels have intrinsic strengths far above their present determined values and that possibly some means for moving in that direction may be found? We may permit ourselves the fond hope that such is the case.

Industrial metals are crystalline aggregates, and a true knowledge of the nature, not only of the crystal, but also of the aggregate, is of fundamental importance to the investigator. To understand the structure of pure metallic crystals is much easier than to appreciate the manner in which crystals of complex solid solutions are built up. There is much we do not know, but since the original classical work of Carpenter and Elam on the growth and properties of single metallic crystals, our knowledge of the individual crystal has greatly increased, and we are better able to understand the properties of the aggregates. Indeed, one great theoretical advance has resulted from this new work, in that it is not now found necessary to postulate a film of under-cooled liquid metal as existing between the several crystals of the aggregate. Such a hypothetical film constituted a theoretical panacea, since it was found too easy to attribute the requisite properties to this film for explaining many problems. Nevertheless, the author would be the first to appreciate the value of Rosenhain's advocacy of this theory from the point of view of its discussion and research-provoking character. Whilst, however, our knowledge is being further increased, and largely by the X-ray method of attack due primarily to the efforts of Sir W. H. Bragg, Hull, Debye and Scheerer and Westgren, we cannot yet be said to understand completely the nature of the crystalline matter of which our metals consist.

To Professor Desch, F. R. S. of the Sheffield University, you were recently indebted for an extremely interesting discussion³ upon the growth of metallic crystals in the light of knowledge extant, and many directions were indicated in which investigations are required.

The eternal problem as to why quenching hardens steel has recently been discussed in a very interesting manner by Jeffries in the last Campbell Memorial Lecture, but can it be said that finality is reached?

³Professor Cecil B. Desch, Lecture before the American Institute of Mining and Metallurgical Engineers, 1927, February.

Again, take for instance, the effect of cold work. Why is the hardness of a metal increased as a result of cold deformation? Why is this effect, in the case of certain austenitic steels, accompanied by a change of phase? It would be easy to write at considerable length concerning what possibly happens, but to the author it would seem profitless to do so, since our knowledge of the atom, of interatomic forces, and consequently of the nature of cohesion, is not, as yet, sufficiently complete.

The limitation of our ability to understand completely many of the problems occurring as regards ferrous alloys at high temperature, is well illustrated by the state of our knowledge concerning the mechanism of the formation of graphite in pig iron. The author's view⁴ is that the material collecting in the bath at the bottom of the blast furnace consists of an impure saturated solution of carbide in iron. As this cools down to the freezing range, carbide is thrown out of solution, which simultaneously dissociates into iron and carbon, with the production of kish. The iron then freezes, the eutectic splitting up into austenite (solid solution) and carbide, which latter constituent, controlled by the prevailing conditions of rate of cooling and composition, either persists or dissociates. Further cooling causes the gradual precipitation of further free carbide, which is governed by considerations similar as regards stability as the carbide separated at the eutectic change point. When we arrive at the temperature at which the pearlite forms we still have the solid solution of eutectoid composition, which now resolves itself into carbide and free iron. The carbide will, again, either dissociate, with the production of perfectly soft pig iron, free from combined carbon, or will persist, and be recognized as the pearlite in the final iron. Satisfying as this is to the author's mind, it apparently by no means meets with general acceptance. R. Ruer⁵ claims that as a result of studying the melting and freezing of white iron, he has obtained evidence of the austenite-graphite eutectic. R. Ruer and F. Goerens⁶ describe the experimental investigation of series of iron-carbon alloys and deduced the direct separation of graphite from solution; they place the graphite eutectic point at 2105 degrees Fahr. (1152 degrees

⁴W. H. Hatfield, "Cast Iron in the Light of Recent Research."

⁵R. Ruer, *Zeitschrift für angewandte Chemie*, Vol. XXXI, 1918, pp. 242-244.

⁶R. Ruer and F. Goerens, *Ferrum*, Vol. XIV, 1917, p. 161.

Cent.). K. Tawara and G. Asahara⁷, as the result of an interesting research, arrive at the conclusion that the carbide dissociates in solution and that the carbon is precipitated as graphite. R. Ruer and J. Biren⁸ consider that the carbon is precipitated as graphite and the same view is again expressed by R. Ruer⁹. Further argument on the same line is to be found in the work of H. A. Schwartz and his collaborators¹⁰. On the other hand the view the author favors meets much support. G. Cesaro¹¹ deduces that the carbide is in solution as such. O. Ruff and W. Borman¹² deduce that graphite is only produced by the dissociation of precipitated carbide. K. Honda and T. Murakami¹³, discussing the results of a valuable research, conclude that graphite is formed as a result of the catalytic effect of CO or CO₂ upon the precipitated iron carbide. L. Northcott¹⁴ also arrives at the conclusion that the carbide is necessarily precipitated prior to the liberation of the graphite, K. Honda and Hikoza Endo¹⁵ give strong experimental support of this view as a result of measurement of volume changes. It will be seen that the whole matter turns on whether or not the carbide of iron is in solution in the liquid steel as such, or whether and to what extent, the carbide dissociates when in solution. This of course, brings up the whole question as to the mechanism of solution of chemical compounds, but it will be seen that until clarity is achieved as regards ideas in that direction, no dogmatic deduction can be made concerning even so apparently simple a problem as the mechanism of the formation of graphite in pig iron and in iron-carbon alloys generally.

In the foregoing observations it has been the author's desire

⁷K. Tawara and G. Asahara, *Journal, College of Engineering, Tokyo*, Vol. IX, 1918, p. 127.

⁸R. Ruer and J. Biren, *Zeitschrift für Anorganische und Allgemeine Chemie*, Vol. CXIII, 1920, p. 98.

⁹R. Ruer, *Zeitschrift für Anorganische und Allgemeine Chemie*, Vol. CXVII, 1921, p. 249.

¹⁰H. A. Schwartz, *Transactions, American Institute of Mining and Metallurgical Engineers*, 1922.

¹¹G. Cesaro, *Journal, Iron and Steel Institute*, Vol. 1, 1919, pp. 447-455.

¹²O. Ruff and W. Borman, *Ferrum*, Vol. XII, June, 1915, p. 124.

¹³Kotaro Honda and T. Murakami, *Science Reports of Tohoku Imperial University*, Vol. X, September, 1921, p. 273.

¹⁴L. Northcott, *Foundry Trade Journal*, June 19, 1924, pp. 515-521.

¹⁵Kotaro Honda and Hikoza Endo, "On the Volume Change During Solidification in Cast Iron and Pure Iron," *TRANSACTIONS, American Society for Steel Treating*, Vol. IX, 1926, p. 967.

to reiterate and to emphasize how great indeed is the field awaiting exploration by the investigator, and how essential it is to do all that can possibly be done, to see that the suitable men have adequate encouragement and resources. Physics and chemistry, if indeed one can look upon chemistry as other than a branch of physics, are the basic sciences upon which industries depend for their gradual evolution to a better state of things, and, indeed, at times, for their preservation and even for their creation. These basic sciences and the men responsible for them should be honored and supported. This is one of the author's principal deductions. It has also been said quite truly that the scientific man who wishes to apply science to industry should endeavor to understand the human element in industry; that is rather a difficult requirement, since it involves the necessity that a mind engaged in looking for absolute truth, shall at the same time maintain full appreciation of, if one dare say it, the element of "original sin." Surely it can be claimed as the further deduction that industry generally should learn to know, to appreciate and to make the best use of the scientist.

Time may come, but not before "Homo Sapiens" is on the decline, when all natural phenomena have been observed and duly docketed. Then, will be an opportunity for one of your wonderful American card index systems, and in the words of Professor E. W. Hobson, F. R. S.¹⁶ "Completely rationalized physics and chemistry would contain within themselves, in the form of postulates, every element which could be supplied by physical observation, and would no longer be dependent for their future progress upon the work of the experimenter. Laboratories would then be useful only for illustrative, didactic, and suggestive purposes, just as drawings and models are still used in geometry, but they would no longer hold their present indispensable position in relation to research."

The author might add that in that golden age, there need be no distinction between pure and applied science or between theory and practice.

SECTION II

STEEL MAKING

Although the manufacturing processes utilized for producing

¹⁶Professor E. W. Hobson, "Science and the Nation," Cambridge University Press, 1917.

steel from the raw materials cannot be described as being scientifically exact, they are, in each instance, approaching that condition. Whereas until comparatively recently, it was usual to speak of the "art" of steel-making, today it can be stated that the physical chemistry of the processes is being gradually mastered. Whilst some of the reactions are incompletely interpreted, some of the more important are sufficiently well understood. On the other hand, the effect of the reactions upon the constitution of the resultant steels is far from explored, and this is particularly marked as regards the origin and nature of the non-metallic matter found within the structure and also as regards the composition, quantity and effect of the gases remaining in the steel. The author, therefore, feels that he can usefully discuss these matters in the hope of directing increased attention to them. The processes most largely used in the production of the higher grade steels are, the crucible, acid open-hearth and electric processes.

CRUCIBLE STEEL

The crucible process is still in use in Great Britain for the production of the special "tool" steels, particularly for the production of high speed steel. The process is very simple. The specially selected pure raw materials are melted in a highly refractory fireclay crucible. The fireclay is rendered stiff enough at the high temperatures by the admixture of a small proportion of coke dust. Thus the charge tends to take up a little carbon from the crucible and also, owing to the permeability of the crucible walls to the furnace gases, a little sulphur is also taken into the steel. Apart from these effects, it can be considered that "what you put into the pot, comes out of it." It is customary to melt the charge and then to retain the crucible in the furnace for the metal to acquire the necessary superheat, during which latter period a slight reaction takes place between the metal and the crucible and slag formed on the upper surface of the metal, which results in an increase of silicon in the steel and, if sufficient manganous oxide is present in the slag, of manganese also. It is usual to add a little manganese to the crucible a short time before teeming. A little aluminum is usually added as the ingot is poured. The great advantage of the process is that while it is expensive, it is still conducted as an "art." The smallness of the crucible and



Fig. 1—Photograph Showing the Teeming of the Individual Crucible Ingots.

charge enables each ingot to be teemed with care and understanding, thus facilitating the production of the special tool steels free from defects. The smallness of the ingots also reduces the possibility of pronounced heterogeneity through differential freezing, and incidentally prevents the coalescence of non-metallic matter into the larger particles found in heavy ingots. It is of interest to record that the firm founded in Sheffield by Huntsman, the inventor of the process in 1744, and which, being associated with my firms, utilizes our research resources, is still most actively engaged in producing a very superb quality of this steel. Fig. 1 well illustrates the care even now taken in the teeming of the individual crucible ingot.

ACID OPEN-HEARTH PROCESS

In Britain, much of the carbon, nickel, nickel-chromium and nickel-chromium-molybdenum steel is made by the acid open-hearth process which has lent itself admirably for the purpose. Although the flame produced by the combination of the gas and

air, plays over the hearth, the metal becomes covered at an early period with a slag, the composition of which is controllable between sufficiently narrow limits to permit of a reasonably satisfactory control of the process of refining. The special alloys and additions can be conveniently melted into the charge in the furnace; and large casts can be turned out within very narrow ranges of composition. By synchronizing the production of the steel in two or three furnaces, the largest ingots required can be effectively made. It is essential in this process to use only the low sulphur and phosphorus irons, since these elements are not eliminated, the reactions centering round the elimination of carbon, silicon and manganese by reaction with a slag consisting essentially of ferrous silicate, in which the oxides of iron are kept at high values during the oxidation period, by the addition of iron ore. A cessation in the addition of the ore, coupled with the maintenance of high temperatures, results in the reduction of the iron content of the slag with an attendant increase in the silica content thereof. When the silica content passes a certain limiting value¹⁷, silicon and manganese begin to be reduced and pass into the steel, and are available for bringing about a deoxidation of the metal. In the best practice, this stage of the reactions is reached and maintained for some time previous to tapping. It cannot, perhaps, be said that it is established that even under such conditions, deoxidation is obtained to the extent which is really desirable. The ingot shown in Figs. 3 and 4 was produced from an acid Siemens-Martin steel charge, which fulfilled the best conditions according to present views.

It will be clear from these observations that, compared with the acid open-hearth process, the basic open-hearth process falls short in not giving equal facilities for deoxidation.

ELECTRIC STEEL MAKING PROCESSES

Force of circumstances and intrinsic advantages have resulted in the electric arc furnaces (either Heroult or Greaves-Etchell) being extensively utilized in Sheffield for the production of special steels. This process, controlled in the best technical manner, is ahead of any other process as regards the excellence of the steel produced. It is admirably adapted for the production of

¹⁷McWilliam and Hatfield, *Journal, Iron and Steel Institute*, Vol. 1, 1902.

steels rich in special elements. The hearths are basic-lined, and after the scrap is melted, the first slag, which is rich in oxide of iron, is removed. A refining slag, essentially lime, is then produced, and under this slag, refining is effectively achieved. Steels made by this process need not have a sulphur or phosphorus content exceeding 0.01 per cent, and if deoxidation is continued to the desirable stage, the steel is remarkably free from "inclusions." Care is always taken not to over-heat the bath under the oxidizing slag, since otherwise gas troubles are caused, which are extremely difficult to eradicate. With suitable electric furnace equipment, and without undue haste in process, the quality of product obtainable is remarkable. The author anticipates great extension in the production of electric steel.

NONMETALLIC INCLUSIONS AND GASES FOUND IN STEEL

The nonmetallic inclusions found in all steels are now receiving attention both in America and in Europe. It is realized that they militate against the fullest advantage being taken of the intrinsic mechanical characteristics of the material. In the first place, they tend to form, when segregated, definite weaknesses in the otherwise strong and ductile material; in the second place, they tend to affect the form and orientation of the final constituents. In the former case, we notice "ghosts" exaggerated at times to form actual discontinuities; in the latter case, the effect is to be seen in a lessening of the ductility when tests are made other than coincident with the direction of deformation during fabrication. They consist of two types; "sulphides" which are the direct result of the amount of sulphur in the steel; hence the desirability in the acid processes of using materials of the lowest sulphur content, and in the basic processes of reducing the element to the lowest values possible under the circumstances. The composition and time and manner of the formation of the sulphides finally found in the steel form the subject of an important research at present being conducted by Dr. Andrew of Glasgow for the Ingot Committee of the Iron and Steel Institute. The full discussions which led to the institution of that investigation disclosed such an unsatisfactory state of knowledge in this field that the author considers there is little that can meanwhile be usefully stated. It would, however, appear that the manganese added to

the liquid steel results in the formation of insoluble sulphide of manganese, most likely containing residual sulphide of iron. To what extent this manganese sulphide joins up with the silicate inclusions is not known.

The other type of inclusion, which apparently is governed by the physical chemistry of the steel-making process, might be designated "slag and oxide inclusions." It is largely held that they are traceable to the oxygen content of the liquid metallic bath.

It is held that if a slag containing oxide of iron is superimposed on a bath of liquid iron, some oxide of the iron will go into solution in the metal. It is not known, however, to what extent the presence of carbon and other elements in the bath affect the equilibrium value for oxide content, and this knowledge is necessary before present accumulating knowledge can be applied to steel-making processes. Austin¹⁸ seems to have satisfactorily established that pure liquid iron can take up 0.24 per cent of oxygen, and Tritton and Hanson¹⁹ established that liquid iron at 2785 degrees Fahr. (1530 degrees Cent.) would take up 0.21 per cent of oxygen, and C. H. Herty²⁰ and his collaborators have shown that the solubility increases to 0.304 per cent at 2910 degrees Fahr. (1600 degrees Cent.), and 0.452 per cent at 3090 degrees Fahr. (1700 degrees Cent.). The latter workers indicate that in calcium-iron oxide slags, the content of lime may vary over a wide range without affecting the solubility of the oxygen. Thus, in the absence of carbon, a definite solubility of FeO of some magnitude appears to be determined. C. H. Herty and J. M. Gaines²¹ claim and the author agrees with them, that since the solubility of the oxygen is greater with the temperature, that does point to the oxygen being present as a compound and not in simple solution. Tritton and Hanson give a value of 0.05 per cent oxygen as representing the maximum solid solubility. Much of the large tonnage of mild steel that is made, is tapped with the slag rich in oxide of iron, and the manganese and silicon, alloyed with iron, are added in the solid form to the liquid steel as it issues into the ladle. As-

¹⁸Mr. Austin, *Journal, Iron and Steel Institute*, Vol. II, 1915, p. 157.

¹⁹F. S. Tritton and D. Hanson, "Ferrous Alloys Research," *Journal, Iron and Steel Institute*, Vol. CX, No. II, 1924, p. 90.

²⁰C. H. Herty, *Carnegie Institute of Technology, Mining and Metallurgical Investigations, Bulletin 34*, 1927, pp. 1-66.

²¹C. H. Herty and J. M. Gaines, *American Institute of Mining and Metallurgical Engineers, February*, 1928.

suming, therefore, that oxide of iron is in solution in the liquid steel, the reaction with the manganese presumably produces insoluble manganous oxide, which must obviously be dispersed through the liquid in the ladle in an extremely fine state of division. The silicon also added, should produce insoluble silica. The present view is that thus the manganous silicate is produced from the union of these two oxides, which has been considered to constitute what is believed to be the most serious form of non-metallic inclusion. The incompleteness of knowledge on this subject, however, is illustrated by the fact that the work of J. H. S. Dickenson²² disclosed that some of the silicates, isolated from acid open-hearth steel, did not consist entirely of manganous silicate, but were most probably really a double silicate of manganese and iron. Dickenson separated the inclusions from the steel by dissolving away the metal in nitric acid. He obtained residues from several types of steel which disclosed very interesting results:—

Table I

Residue obtained by complete solution of normal samples	Per Cent			
	SiO ₂	MnO	FeO	Al ₂ O ₃
Large Ni-Cr steel ingot	49.0	41.5	1.9	9.5
Large Carbon steel ingot	40.5	28.8	18.0	11.5
Large Ni-Cr steel forging	53.7	40.2	4.7	trace
Large Ni-Cr steel ingot	55.0	33.0	14.5	1.6
15-cwt. Ni-Cr steel ingot	72.0	22.5	3.9	1.1
12-ton Ni-Cr steel ingot	54.5	40.9	4.1	..

The percentage weight of the slaggy matter in the steel was apparently of the order of 0.016 to 0.04 per cent. Colclough, in discussing Dickenson's research, indicated that solution in 10 per cent H₂SO₄ gave a higher yield of slaggy matter, and his results are quoted in Table II.

Following Dickenson's method, the author has obtained the results shown in Table III.

It is, therefore, not quite clear as to what the nature of the reaction is between the added manganese and the oxygen which is held to be present in the liquid steel, or whether the inclusions necessarily originate as just suggested.

Clearly, however, it is reasonable to suppose that if the steel is "finished" in this manner, the amount of the silicate present in the finished steel will be influenced by the composition of the

²²"A Note on the Distribution of Silicates in Steel Ingots," J. H. S. Dickenson, *Journal, Iron and Steel Institute*, Vol. CXIII, No. 1, 1926, p. 177.

Table II

Solvent	10 Per Cent HNO ₃	10 Per Cent H ₂ SO ₄
Residue per cent	0.0147	0.0296
SiO ₂	48.9	41.4
FeO	18.9	17.2
MnO	32.1	41.2

slag, since the oxygen content of the steel depends upon the equilibrium values. These comments apply to both the acid and to the basic processes when operated under the conditions as above described. We are indebted to Ledebur for first pointing out that the oxides, produced in deoxidation by the manganese and silicon,

Table III

Steel	Per Cent slaggy matter	SiO ₂	FeO and other oxides	MnO
Acid Siemens	0.034	48.2	3.1	42.0
Acid Siemens	0.036	60.5	4.4	30.7
Bessemer	0.065	63.0	4.0	33.0
Bessemer	0.034	46.0	2.0	52.0
Electric	0.05	51.0	34.0	15.0
Crucible	0.024	50.0	20.0	30.0

were not likely to separate themselves readily from the liquid metal²³.

It will be seen that an adequate handling of this problem demands satisfactory methods of determining, by analytical methods, not only the amount of oxygen in the steel, but also the form in which it occurs. It may exist as oxides of iron, manganese, silicon, chromium and other elements; largely occurring as silicates of variable composition; and it may also occur as the oxides of carbon, CO and CO₂. This latter view is discountenanced in certain directions, but the author considers the whole matter worth re-consideration.

The gaseous oxides of carbon cannot be considered, except along with the general question of the gaseous content of steel.

Knowledge here is extremely meager, as will be shown, and this is largely due to the difficulty experienced in devising suitable methods of determining the amount of oxygen present. So important is this matter that the author considers it desirable to review the evolution of the methods.

²³Dr. Ledebur, *Stahl und Eisen*, Vol. 15, 1895, p. 376.

METHODS OF OXYGEN DETERMINATION

Many different processes have been used with this object, and they can be mainly classed under two headings:—

- (1) Methods to obtain a residue of oxides from the steel.
- (2) Methods where an attempt is made to decompose the oxides, with subsequent measurement of the gaseous products of the decomposition.

The process of Troilus²⁴ was one of the first in the field, and this consisted of treating the steel with a neutral solution of ferric chloride with the subsequent separation of an impure residue. This residue—sulphides, phosphides, oxides and silica—was weighed and allowances made for impurities. Eggertz²⁵ estimated oxygen by dissolving the steel in iodine and separating the non-metallic residue. The Pourcel²⁶ method [temperature indefinite, but probably about 1110 degrees Fahr. (600 degrees Cent.)] consisted of heating steel drillings in a stream of chlorine until all the iron was volatilized and driven off as ferric chloride. Schneider²⁷ used bromine as a solvent for steel in these determinations, and this reagent was also used by Wust and Kirpach²⁸. All these methods were very ably criticized by Oberhoffer, Keutmann, Scherer and Strauch²⁹, and by Oberhoffer, Keutmann, Hessenbruch, and Ammann³⁰ in 1925 and 1926. Bender³¹ appears to have been the first to use the hydrogen reduction process, which, with modifications, came to be known as Ledebur's³² method, and was used to a great extent by subsequent workers. In this process, drillings of the steel are heated in a current of hydrogen at a temperature of 1830 degrees Fahr. (1000 degrees Cent.), or thereabouts, and the resultant water vapor is absorbed and weighed.

²⁴Dr. Troilus, *Jernkontorets Annaler*, Vol. XXXIX, 1884, p. 432.

²⁵Dr. Eggertz, *Polytechnique Journal*, Vol. 88, 1868, p. 119.

²⁶Pourcel, *Journal*, Iron and Steel Institute, 1882, pp. 509-518.

²⁷Schneider, *Oest. Zeitschrift für das Berg-, Hütten, und Salinenwesen*, XLVII, pp. 257-60.

²⁸Wust and Kirpach, *Chemistry and Industry*, 550A, 1922.

²⁹Scherer and Strauch, *Stahl und Eisen*, Vol. 45, 1925, pp. 1555-63.

³⁰Oberhoffer, Keutmann, Hessenbruch and Ammann, *Stahl und Eisen*, Vol. 46, 1926, pp. 1045-9.

³¹Bender, *Dinglers Polytechnisches Journal*, Vol. CCV, 1873, p. 331.

³²Ledebur, *Stahl und Eisen*, Vol. XV, 1895, p. 376.

Pickard³³, McMillen³⁴, Austin³⁵, Oberhoffer³⁶, Schmitz³⁷, Cain and Pettijohn³⁸, and Rooney³⁹, all used this process in slightly varying forms. The disadvantage of the method is that it does not obtain the whole of the oxygen from the steel; Oberhoffer and his co-workers have shown that only oxide of iron is reduced with certainty, while silica remains unaffected and manganous oxide is only decomposed slowly after prolonged heating and passage of hydrogen. In 1909, Goutal⁴⁰, published a method whereby steel was dissolved in copper potassium chloride solution and the gases liberated from the steel were carried by a stream of nitrogen into an absorption train. In 1919, however, this method was shown by Cain and Pettijohn⁴¹ to be inaccurate. The Pfeifer-Schiessl⁴² method consisted of heating at 2100 to 2280 degrees Fahr. (1150 to 1250 degrees Cent.) the steel and withdrawing the gases presumed by them to be formed by reaction between carbon and oxides in the steel, by means of a vacuum pump. This method has been modified to the extent of melting the steel (with or without antimony and tin) by Baraduc-Muller⁴³, Goerens and Pacquet⁴⁴, Jordan and Eckman⁴⁵ and Hessenbruch and Oberhoffer⁴⁶, and it is claimed that complete decomposition of the oxides of iron, manganese and silicon occurs under the correct conditions. The Dickenson⁴⁷ method is a reversion to solution of the steel, and consists in dis-

³³Pickard, *Journal*, Iron and Steel Institute, Carnegie Scholarship Memoirs, Vol. V, 1913, p. 70.

³⁴McMillen, *Iron Age*, Vol. XCI, 1913, pp. 308-9.

³⁵Austin, *Journal*, Iron and Steel Institute, Vol. 92, 1915, pp. 157-161.

³⁶Oberhoffer, *Stahl und Eisen*, Vol. XXXVIII, 1918, pp. 105-110.

³⁷Schmitz, *Stahl und Eisen*, Vol. XXXVIII, 1918, pp. 541-2.

³⁸Cain and Pettijohn, Bureau of Standards Publication No. 118, 1919.

³⁹Rooney, *Journal*, Iron and Steel Institute, Vol. 110, 1924, p. 122.

⁴⁰Goutal, *Comptes Rendus*, Vol. 148, 1909, p. 988.

⁴¹Cain and Pettijohn, Bureau of Standards Publication No. 126, 1919.

⁴²Pfeifer and Schiessl, *Stahl und Eisen*, Vol. 44, 1924, p. 113.

⁴³Baraduc and Muller, *Journal*, Iron and Steel Institute, Carnegie Scholarship Memoirs, Vol. VI, 1914, pp. 216-230.

⁴⁴Goerens and Pacquet, *Ferrum*, Vol. XII, 1914-15, pp. 57-64 and 73-81.

⁴⁵Jordan and Eckman, Bureau of Standards Publication, 1925, pp. 445-482.

⁴⁶Oberhoffer, *Stahl und Eisen*, 1928, p. 486.

⁴⁷J. H. S. Dickenson, "A Note on the Distribution of Silicates in Steel Ingots," *Journal*, Iron and Steel Institute, Vol. CXIII, No. 1, 1926, pp. 177-96.

solving a piece in dilute nitric acid with subsequent treatment of the residue to remove carbon and silicic acid.

It will, therefore, be clear that no method has yet been devised which is completely satisfactory for giving the total oxygen, unless the method of withdrawing the whole of the gases from liquid steel be considered as such. This method, however, labors under the disability that it assumes but does not prove that under the conditions of the determination, the whole of the oxygen has come off. It is necessary also to devise a process for determining the amount of CO and CO₂ in the steel at ordinary temperatures, the great difficulty being to be sure that the gases taken really represent the conditions in which they exist in the steel.

GASES IN STEEL

When one really considers the present position as regards knowledge, matters must be considered to be thoroughly obscure. Charpy and Bonnerot⁴⁸ found 30 per cent of CO in the gases extracted. Boudouard⁴⁹ found CO and CO₂ together with nitrogen and hydrogen, given off by merchant iron at 2010 degrees Fahr. (1100 degrees Cent.) This is confirmed by Belloc's⁵⁰ work. Baker⁵¹, as the result of a very prolonged and interesting research, gives the composition of the gases given off, as varying with the temperature, but agrees that they are always carbon monoxide, nitrogen and hydrogen; he also shows that sound steel free from blow holes, contains more gas than blown steel. According to Donaldson⁵² carbon monoxide and hydrogen predominate, the other gases being there in a total quantity of less than 2.5 per cent; he indicates that the presence of silicon and manganese decreases the carbon monoxide and increases the hydrogen. Stadeler⁵³ has similar views. Allemann and Darlington⁵⁴ consider the solubility of the gases in the steel is decreased by the presence of manganese,

⁴⁸Charpy and Bonnerot, *Comptes Rendus*, Vol. 152, 1911, p. 1247.

⁴⁹Boudouard, *Comptes Rendus*, Vol. 145, 1907, pp. 1283-4.

⁵⁰Belloc, *Comptes Rendus*, Vol. 118, 1907, pp. 244-5 and 145 and pp. 1280-3.

⁵¹Baker, *Journal*, Iron and Steel Institute, Carnegie Scholarship Memoirs, 1909.

⁵²Donaldson, *Journal*, Iron and Steel Institute, Carnegie Scholarship Memoirs, 1916.

⁵³Stadeler, *Stahl und Eisen*, Vol. 37, 1917, pp. 1075-7, and *Zeitschrift für angewandte Chemie*, 31, Ref. 168, 1918.

⁵⁴Allemann and Darlington, *Journal*, Franklin Institute, February, 1918, America.

silicon, aluminum or chromium. McCance⁵⁵ considers the problem but omits to deal with the part played by hydrogen. In a later work, Baker⁵⁶ showed the gases to consist almost equally of carbon monoxide and hydrogen, but the quantity differs with the condition of the steel. Amsen and Willners⁵⁷ confirm this. Lobley and Betts⁵⁸ experiments are of interest. Braune⁵⁹ indicates that nitrogen is present and in the form of nitride.

Sieverts and Krumbhaar⁶⁰ indicate that nitrogen is taken up at a temperature of 2192 degrees Fahr. (1200 degrees Cent.) but not evolved again when the steel is heated in vacuum. The solubility at high temperatures is a matter of definite disagreement and in this respect the work of von Malitz⁶¹ and Sieverts⁶² should be compared. Sieverts studied the solubility of gases in molten metal and indicates that hydrogen increases in solubility with the temperature, which would be a remarkable fact.

Heroult⁶³ and Goerens⁶⁴ state that cold steels contain little gas, and that blow holes are formed by reaction between the carbide of iron and oxide of iron present. Johns⁶⁵ takes the same view. Parravano and Scortecce⁶⁶, Parravano and Del Turco⁶⁷ and Klinger⁶⁸ all consider that the reaction between the carbide and oxide is responsible for the carbon monoxide and carbon dioxide given off. The present author takes the opposite view, i.e., that this re-

⁵⁵McCance, General Discussion on "Occluded Gases in Metals," *Journal*, Faraday Society, November, 1918.

⁵⁶Baker, General Discussion on "Occluded Gases in Metals," *Journal*, Faraday Society, November, 1918.

⁵⁷Willners, *Jernkontorets Annaler*, Vol. 110, 1926, pp. 107-124.

⁵⁸Lobley and Betts, *Journal*, Iron and Steel Institute, Vol. III, No. 1, 1925, p. 225.

⁵⁹Braune, *Revue de Metallurgie*, 1907, p. 834.

⁶⁰Sieverts and Krumbhaar, *Berichte Deutsche Chemiker Gesellschaft*, Vol. 43, 1910, pp. 893-900.

⁶¹Von Malitz, *Bulletin*, American Institute Mining Engineers, 1907, pp. 691-726.

⁶²Sieverts, *Zeitschrift für Physikalische Chemie*, L. XXVII, pp. 591-613.

⁶³Heroult, *Journal*, American Electrochemical Society, Vol. 17, 1910, pp. 135-7.

⁶⁴Goerens, *Metallurgie*, Vol. 7, 1910, pp. 384-5.

⁶⁵Johns, General Discussion on "Occluded Gases in Metals," *Journal*, Faraday Society, November, 1918.

⁶⁶Parravano and Scortecce, *Annali di Chimica Applicata*, Vol. 14, 1924, pp. 3-17, and *Chimie et Industrie*, Special No. 312, 1924.

⁶⁷Turco, *Atti. Acad. Lincei*, Vol. 32, II, 1923, pp. 373-6.

⁶⁸Klinger, *Stahl und Eisen*, Vol. 46, 1926, pp. 1245-54, 1284-8, 1353-6.

action does not account for the evolution of the gas which causes the blow holes. In an interesting paper Andrew⁶⁹ suggests the gases are in combination in the iron, while from Rosenhain⁷⁰ we have a suggestion that they are present in the under-cooled liquid film existing between the crystals. This latter view, of course, depends upon the existence or otherwise of the amorphous film.

Taking a general view of the matter, however, there is really no definite agreement upon the subject, except that quite a strong body of opinion is in favor of the reaction theory as regards the production of the carbon monoxide and carbon dioxide. Such a view, however, does not take into consideration the hydrogen content and there is undoubtedly unanimity of opinion as regards the proportion of hydrogen present. Any satisfactory explanation, therefore, of the evolution of these gases which produce the blow holes, must contain adequate explanation of the part played by the hydrogen.

Looking at the matter from the steel making point of view, there are two outstanding facts which should be taken note of and which can undoubtedly be confirmed by anyone. The first is that in the acid open-hearth process, whilst the oxide of iron is still at a high value in the slag, and, therefore, it is to be presumed according to a certain view that oxide of iron is in solution in the iron, samples can be taken from the bath which freeze perfectly solid and free from blow holes. The next point is that in the electric process, if the bath is over heated in the early stages of the process, the metal becomes so charged with gas that even 1 per cent of silicon is insufficient to prevent the evolution of gas on freezing.

The author's object in reviewing this phase of steel manufacture has really been to draw attention to the great need for a number of investigators to concentrate upon these problems. We know little of the extent of the solubility of the gases in question in the steels in this range of temperature, and we know little concerning the solubility of oxide of iron in baths of commercial steel, containing as they do, carbon, phosphorus and other elements.

⁶⁹Andrew, *Journal, Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1911.

⁷⁰Rosenhain, General Discussion on "Occluded Gases in Metals," *Journal, Faraday Society*, November, 1918.

TEMPERATURE MEASUREMENTS

The work done by the Bureau of Standards Committee and individual American workers is known to you, and it is therefore proposed to confine these observations to personal experience.

For liquid steel temperature determinations, it is usual to employ distance pyrometers of the optical type. The two chief types of optical pyrometer are, (1) the disappearing filament and (2) the Wanner polarizing type. The latter is probably the more popular instrument, but both are equally adaptable. The following remarks apply particularly to the polarizing type.

The Cambridge optical pyrometer instrument may be regarded as a photometer, in which, by simply rotating the analyzer attached to the eyepiece, a beam of selected monochromatic light from the hot body is matched in intensity against a beam of similar light from an incandescent electric lamp. The current through the lamp is standardized for each instrument. The instrument has generally two ranges, 1290 to 2550 degrees Fahr. (700 to 1400 degrees Cent.) and 1650 to 3630 degrees Fahr. (900 to 2000 degrees Cent.), and for the latter range an absorbing screen is moved in front of the objective. If the instrument is used on steel in the open, the correction must be added for divergence from "black body" conditions.

It is proposed to consider the degree of accuracy of the instrument, given an ideal hot body and plenty of time in which to make the temperature observations. Such conditions may be obtained with the standard amyl acetate flame as the "hot body" and the instrument set up in the usual way as if for calibrating purposes. With constant setting of the ammeter, readings may not be regularly obtained with greater accuracy than plus or minus 0.40 degrees angular deflection. This is equivalent to plus or minus 3 degrees Cent. at temperatures 2370 to 2550 degrees Fahr. (1300 to 1400 degrees Cent.). At higher temperatures, the temperature scale on the instrument becomes more crowded, but it is considered that a rotation of the pointer through one angular degree at the higher temperatures, makes more difference to the intensity of the light seen through the instrument, than a similar rotation at the lower temperatures. This somewhat counteracts the crowding of the scale, and thus it is still possible to obtain an accuracy of about plus or minus 5 degrees Cent. Slight inac-

inaccuracies in the setting of the ammeter, which gives a measure of the filament current, will cause definite small errors in temperature measurements.

A check on the instruments is frequently made by comparison with a rare metal thermocouple; the hot junction of the couple is mounted in the face of a refractory disk, placed in an electrically heated tube, so that it may be sighted upon through the end of the tube with the optical instrument. Suitably placed diaphragms serve to obtain, as near as possible, black body conditions in the neighborhood of the heated disk.

An exact measurement of liquid steel temperatures is only possible under very precise conditions. In steel works the conditions are far from ideal, and are usually uncontrollable, so that, at the best, the observations should only be considered as an approximation.

The author would now like to draw attention to the very important matters of determining and controlling the temperatures of liquid steel. The actual temperatures existing during the reactions are fundamentally important, and are dealt with in practice on empirically practical lines. The casting temperature is, however, so important as to be a determining factor. The temperatures of liquid steel are best determined by the optical pyrometer (generally the Cambridge) and the total correction for black body conditions at such temperatures is usually at present made uniformly 125 degrees Cent.

Probably the best conditions for temperature determinations, obtain during the teeming of ingots, or castings, from the ladle. There one has a steady stream of liquid steel. Fumes, caused say by the burning of washes used in the molds, etc., often interfere with the observations, sometimes seriously, but in general such effects clear away before the complete casting of each ingot, and a clear field is obtained for a sufficient length of time to take a reading.

In almost all cases, it is not possible to fill the field of the instrument when sighting on ladle streams, but it is considered that this has little influence on the observations, except that it makes it more difficult to match the two halves of the photometric field. Difficulties arise from polarization, caused by the curved surface of the stream, and failure to view the stream normally to

the surface, and also the possible chilling of the outside layer of metal, may introduce further errors. It has been concluded by Greenwood⁷¹ that the errors due to both these causes are not usually more than 20 degrees Cent., but that under certain conditions, they may reach 40 degrees Cent. In each of these cases, the effect is to lower the observed temperature. It has been noted that when the ladle stopper is not full open, the stream, instead of being steady and of uniform cross section, becomes straggly, and in reality consists of a number of separate fine streams. In such cases, the apparent temperature rises to the extent of 10 to 20 degrees Cent., and this is considered to be due to inter-reflection of light between the various component parts of the stream, so that the conditions are not truly free radiating.

The observation of the temperature of tapping streams from open-hearth furnaces presents no great difficulty. The steel is usually sighted upon as it passes over the end of the launder. Fumes do not interfere to any appreciable extent.

It is essential that readings be made on the center of the side of the stream exposed to view, in order to obviate possible effects of polarization. Usually the lower part of the stream appears hotter when viewed from the side, probably because of reflection from the molten metal of the falling stream, and from the surface of the metal in the ladle. The temperature of the metal issuing from the furnace is not usually constant from start to finish, and in some cases fairly wide variations occur. In order, therefore, to obtain a true indication, it is necessary to take the average of a number of readings. Temperature observations of the slag during tapping, may be taken, but they are considered to have no great value.

It is considerably more difficult to obtain a true indication of the temperature of the stream issuing from an electric furnace. As in the previous case, it is usual to attempt to measure the temperature as the stream passes over the launder, but as the contents of a small furnace are emptied into the ladle in about half a minute, the smartness of the operator is tested to the utmost. In addition, there are apparently, at times variations in temperature between the different portions of the steel forming the heat. It is impossible for an operator to tabulate a series of temperatures at

⁷¹Greenwood, *Journal, Iron and Steel Institute, Carnegie Scholarship Memoirs, 1923.*

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time intervals, and the best that one can do is either observe the temperature of the hottest portion, or attempt to give an average value. The latter method introduces the human element to a definite extent, whilst the temperature of the hottest metal may or may not bear any definite relation to the average temperature. Further, in the case of the electric furnace, the slag comes over with the steel, and it is a very easy mistake to confuse the one with the other when sighting through the instrument. To minimize the chances of sighting on slag, the best position for the operator is either underneath the stage, towards the side of the slag pit (a very risky position, not always possible) or to the rear of the stream by the side of the furnace, sighting on the underside of the stream in each case, but in these positions, there is the possibility of getting a false reading, on account of reflections from other portions of the stream, and from metal in the ladle. An alternative position is by the side of the stream. Fumes may interfere to a greater extent than in the case of tapping open-hearth furnaces. It is considered that observations on electric furnace tapping streams are generally unreliable, although in some cases, when exceptional conditions obtain, the observer may be confident of his results.

Johns⁷² and Greenwood⁷³ have observed that when teeming steel into two or three molds through a trough, the apparent temperature of the "clean area", on the trough-surface near to the falling stream, is the same as that of the stream itself, but as the field is shifted further toward the end of the trough, the apparent temperature rises, owing to the growth of a surface film having a higher emissivity. It is claimed that the presence of readily oxidizable elements, such as chromium, accentuates this effect. The average difference between the apparent temperatures of trough surface and ladle stream is 25 to 45 degrees Cent. Greenwood also compared the apparent temperature of the ladle stream with that of the surface in the mold, in which fresh metal is continuously exposed, and cooling at a minimum. He found that the stream appeared lower than the plane surface by an amount varying between 10 and 65 degrees Cent. It was claimed that the rise in apparent temperature is again due to the presence of a surface film

⁷²Johns, *Journal*, Faraday Society, 1918, 13, pt. 3.

⁷³Greenwood, *Journal*, Iron and Steel Institute, Carnegie Scholarship Memoirs, 1923.

of oxide. These casts contained 0.5 to 1.5 per cent chromium. It might be suggested that the apparent temperature of a plane surface is the correct one, and that the ladle stream gives low readings, but that this is not so has been shown by comparing the actual observed drop in temperature of the steel when run into the ladle, with the calculated drop in temperature. Greenwood calculated that the temperature should be lowered by 30 degrees Cent. The apparent loss in temperature as measured on (a) the ladle stream and (b) the trough surface, was 30 and 70 degrees Cent. respectively. The readings on the trough surface were therefore concluded to be high.

It is when one attempts to obtain a true indication of liquid steel temperatures, whilst the steel is still in the melting furnace, that the greatest troubles are encountered. These are mainly caused by the variability of furnace conditions.

Considering the open-hearth furnace first, access to the steel itself is impossible, and observations may only be made on the surface of the slag, or on some part of the brickwork of the furnace interior. It is obvious that unless the conditions of working are constant from heat to heat, no definite relation between the apparent temperature of the slag or brickwork can exist. Actually, by altering the working conditions, it is possible to obtain the slag either hotter or cooler than the bath of steel. In addition to this, for the readings on the slag surface to be of any value, the conditions under which they are made must be reproducible, and this is by no means a simple matter.

Among the conditions which influence the apparent temperature of the slag surface in the furnace are the following:—

1. *The variable departure from black body conditions caused by the opening of the door.* The area near to the door will be most affected, and so much so, that Johns has stated that with the gas off, the conditions closely approach to that of a free radiating surface. Away from the door, the effect gradually diminishes with distance.

2. *Reflection from the brickwork and flames.* The apparent slag temperature may be increased or decreased by radiation from the brickwork, depending upon (a) their relative emissivities and (b) their relative temperatures. With gas on, the apparent tem-

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perature of the slag is increased by reflection, both direct from the flames, and indirect from the walls.

Greenwood has carried out an extensive study of the effect of reflection from flames, upon pyrometric observations, and he concluded that the average difference of temperature of the slag, with gas on and off, is 32 degrees Cent. correct to ± 10 degrees Cent. in 88 per cent of the cases. Our experience approximately confirms this average difference, but we are of the opinion that there is an even greater variation than Greenwood found. It is considered wise to eliminate the effect of flames, by making observations during reversals, when the furnace is clear for a brief period. Unfortunately, this limits the frequency of useful observations to that of the reversals, i.e., about every 20 minutes, towards the end of a heat.

3. *The position of the field and viewing angle.* A constant field and viewing angle should be adhered to, to ensure comparative readings. The temperature of the extreme ends of the furnace fluctuates with the direction of the gas, so that observations should preferably be made through the center door.

It may be considered that much has been said with regard to the use of the optical pyrometer, but as hitherto it has provided the only quantitative manner of dealing with the temperatures of molten steel, it was felt desirable to discuss its limitations thoroughly. It fails, not so much in its utility for ensuring consecutive similar temperature effects in an individual works when the observations are made by one operator, but rather loses its value when attempts are made, as is being done at present, to provide essential data of universal application, derived from a number of different works. The manner of use is so important in its bearing upon the figures given.

Fortunately, from the practical point of view, the skill of the best melters, in empirically judging, not only the temperature throughout the process, but also the finishing temperature, is so considerable as to enable the reproduction of standard conditions a practical accomplishment. The difficulty is that until the pyrometry of high temperatures is more developed, the effect of temperature cannot be stated in a sufficiently quantitative way. The melters "instrument" is provided for him in the slag, the composition and temperature of which he controls, and thus by studying

its physical characteristics and general appearance, he has a very good guide. The behavior, too, of the refractory materials of which his furnaces are constructed is also a valuable guide.⁷⁴

Attempts have been made from time to time to develop and apply the thermocouple method, but much more work is still necessary.

From the practical point of view, spoon samples are taken, of various sizes, from the liquid metal bath and judged in various ways. The normal sample after cooling out, is studied for the characteristics of the metal and slag, and provides much useful information.

A larger spoon sample is sometimes employed and the behavior of the surface of the liquid steel studied. The "mirror" test, so called from the appearance of the liquid metal surface, is valuable since the length of time the "mirror" surface is retained, does give at least an empirical idea of the temperature of the steel in the furnace; unfortunately the practical conditions demand absolute uniformity of the conditions, particularly as regards the temperature of the spoon.

It will, however, be perfectly clear that the serious attention of technologists must be directed to this question of taking quantitative observations of temperature.

⁷⁴Fusion "points"—

	Degrees Fahr.	Degrees Cent.
Fireclay	2910-3130	1600-1720
Silica	3000-3090	1650-1700
Magnesite	3630-3810	2000-2100
Chromium	3520-3720	1950-2050
Bauxite	2910-3270	1600-1800
Zirconia	4350-4710	2400-2600
Alundum	3720	2050
Carborundum	decomposes at 4060	2240

(To be continued in April issue of TRANSACTIONS)

Educational Section

These Articles Have Been Selected Primarily For Their Educational
And Informational Character As Distinguished From
Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON SECTION II—PART VII

By F. T. SISCO

Abstract

This installment, the seventh of the present series, describes and illustrates the structure of the three transition constituents in heat treated steel, martensite, troostite and sorbite. By means of representative photomicrographs, it is shown that under certain conditions it is relatively easy to identify martensite and troostite when occurring in the same specimen by the difference in their appearance and etching characteristics. In addition, sorbite usually can be differentiated from granular pearlite in the same specimen, but in most cases it is extremely difficult to detect sorbite in the presence of troostite in tempered steels. These typical structures also show that there may be relatively great differences in appearance in the same constituent as the result of different thermal treatments, even though the Brinell hardness is the same. This description of these three metallographic constituents paves the way for a consideration of theories of hardening which will be discussed in the eighth installment.

It has been repeatedly emphasized in previous installments that when a medium or high carbon steel is cooled very slowly through the lower transformation point, Ar_1 or Ar_{3-2-1} , the essential structural change is from austenite, a solid solution of carbon or

This is the fifteenth installment of this series of articles by F. T. Sisco. The several installments which have already appeared in TRANSACTIONS are as follows: June, July, August, September, November, 1926; January, February, April, June, August, October, 1927; February, April, June, November, 1928; January, 1929.

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iron carbide in gamma iron, to pearlite, an aggregate consisting ordinarily of parallel plates or laminations of ferrite (alpha iron) and cementite (iron carbide, Fe_3C). This is the normal change from a structural condition of stable equilibrium above Ar_1 , to a structural condition of stable equilibrium below this point.

If cooling through the Ar_1 point is accelerated a structure results that is different from the familiar laminated pearlite. The structure resulting from a slightly accelerated cooling is known as sorbite; still more accelerated cooling produces a structural condition known as troostite; and very rapid cooling results in the structure of martensite. From the previous installment it is also evident that accelerating the rate of cooling depresses the Ar_1 point until with extremely fast cooling this point may be depressed below atmospheric temperature and the resulting structure will be austenite. Having viewed in detail the rate of cooling necessary to produce these three constituents, sorbite, troostite and martensite; and the effect of this cooling rate on the lower transformation point; and having described their properties, the next step is to become familiar with their structure and then pass on to the more difficult task, their constitution.

Before taking up the structure of sorbite, troostite and martensite in detail, it should be emphasized again that these three constituents are not definite structural entities of fixed composition and appearance; rather they are structural conditions. All three represent conditions resulting in the passing of the structure from austenite stable above Ar_1 to laminated pearlite, stable below this point. As each represents a transition it is evident that their constitution is exceedingly variable. For example we may have a steel containing 0.75 per cent carbon whose structure as viewed by the microscope is apparently all martensite. On the other hand, we may have a steel containing 1.25 per cent carbon whose structure likewise is all martensite. Under the microscope the two steels look identical; we know, however, that the martensite in these two steels is not identical in constitution because one steel contains 0.50 per cent more carbon than the other. Thus it is plain that martensite may be of variable constitution and oftentimes of variable appearance, while pearlite in contrast to this is of fixed composition (about 0.85 per cent carbon) and usually of characteristic and easily identified appearance.

In the second place we rarely are able to treat a specimen so

the resulting sorbite, troostite or martensite is not adulterated by one of the other constituents. For example we may heat treat two pieces of high carbon tool steel so that the structure is apparently all martensite, as seen by the microscope; but the Brinell hardness of one may be 700 and of the other only 500. If the chemical composition of the two specimens is identical it is evident that in one the martensite is contaminated by considerable troostite.

In consequence of this, in examining and identifying sorbite, troostite and martensite, we must take other factors into consideration beside the general appearance. Before we can state definitely that a structure is troostite we should know first of all how troostite usually looks under the microscope; and next we should know something about the physical properties of the material,—notably the hardness—also the chemical composition, heat treatment and the like. These things aid us in identifying the structure that we see in our polished and etched specimens of hardened, and hardened and tempered steels.

THE STRUCTURE OF SORBITE

If a steel containing about 0.90 per cent carbon is cooled very slowly through the Ar_1 transformation point, so that all of the normal changes take place, and if we examine a prepared specimen of this steel with the microscope we will see the familiar laminated pearlite, characteristic of this normal structural change. If the steel contains free ferrite (hypoeutectoid) or free cementite (hyper-eutectoid) the excess constituent will segregate, during this normal change, in slow cooling through Ar_1 into characteristic masses or as a network at the grain boundaries; in any case a free constituent will be readily distinguishable with the microscope. This normal structure of laminated pearlite, either alone or with excess ferrite or cementite has been described and illustrated in detail in former chapters.

Now if cooling is but slightly accelerated through the Ar_1 point the laminations of ferrite and cementite making up the pearlite are not so distinct. We still are able to detect particles of ferrite and cementite, but the familiar and characteristic laminations have almost disappeared. This structure, which we know as granular pearlite, has also been illustrated and described in former

installments.⁴¹ In the case of any free ferrite or cementite present, we are still able to distinguish this excess constituent, but it may not be segregated into definite grains. In the structure known as granular pearlite, the faster cooling rate has affected principally the appearance of the pearlite giving it a more or less granular form instead of its normal and characteristic lamellae, but has not affected appreciably the appearance or distribution of the excess ferrite or cementite present.

If cooling is still more accelerated a point is reached where the ferrite and cementite making up the pearlite can hardly be resolved at any magnification. In addition any free ferrite or cementite present, unless the excess is very great, can be detected with great difficulty if at all. Unless there is a large amount of the excess constituent present, there has been insufficient time in cooling for this excess constituent to gather at the boundaries of the pearlite grains or to become segregated into well defined masses. The excess ferrite or cementite present will be entrapped—we might say almost emulsified—within the ground mass and we have the structure known as sorbite.

The structure of sorbite is illustrated in Figs. 46, 47 and 48. Fig. 46 is the structure of a one inch bar of 0.40 per cent carbon steel cooled in an air blast from 1500 degrees Fahr. In a transverse section of this bar could be detected sorbite, granular pearlite, free ferrite, and lamellar pearlite with both fine and coarse lamellae. The area, photographed as Fig. 46, contains a few patches of free ferrite, the white areas near the left side of the photograph; and a few small areas of laminated pearlite, one of which can be noticed near the ferrite grains at the left, and another at the bottom of the photograph. The light gray areas near the top of the photograph, and also at the right and near the bottom, consist principally of granular pearlite. At the magnification used ($\times 500$) it is just possible to detect that these areas are made up of more than one constituent. The dark gray areas in Fig. 46, especially at the extreme top, near the center, and at the lower right, are sorbite. It would be difficult to resolve these areas into ferrite and cementite at any magnification. The Brinell hardness of this specimen, which structure is shown in Fig. 46, was 197.

Fig. 47 is the structure of a small piece of a 0.30 per cent

⁴¹Described in Section I, Part IV, TRANSACTIONS, Vol. 10, Page 468, and illustrated in Section II, Part II, TRANSACTIONS, Vol. 13, Page 314.

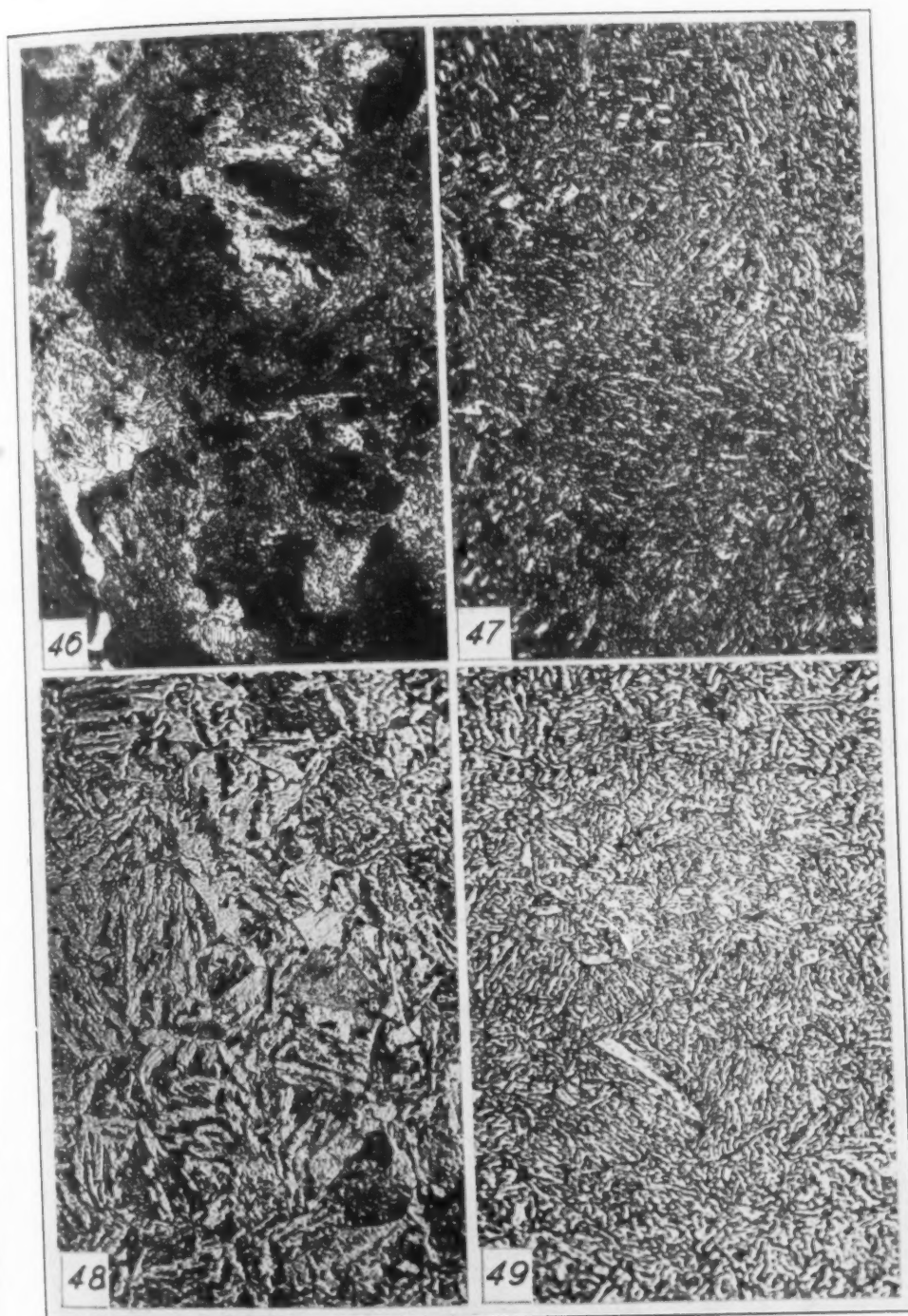


Fig. 46—Photomicrograph Showing Sorbite, Granular Pearlite, Laminated Pearlite and Free Ferrite. Brinell Hardness 197. $\times 500$. Fig. 47—Photomicrograph Showing Fine Grained Sorbite. Brinell Hardness 235. $\times 500$. Fig. 48—Photomicrograph Showing Coarse Grained Sorbite. Brinell Hardness 229. $\times 500$. Fig. 49—Photomicrograph Showing Coarse Grained Martensite. Brinell Hardness 654. $\times 500$. All Specimens Etched in Alcoholic Nitric or Alcoholic Picric Acid.

carbon, 3.50 per cent nickel steel quenched in oil and tempered at 1300 degrees Fahr. The structure here is a fine grained sorbite,⁴² wholly free from laminated pearlite and almost free from granular pearlite. Due to the low percentage of carbon in this steel there are some small white particles of free ferrite present, but these particles are very small and well distributed in the sorbite matrix. It will be noted that in Fig. 47 no distinct grains are present, only the small particles of ferrite in what appears to be a uniform ground mass. The Brinell hardness of this specimen was 235.

Fig. 48 is the structure of a piece of 0.35 per cent carbon, chromium-molybdenum steel sheet 0.125 inch thick, cooled in air from 1750 degrees Fahr. The specimen was held at temperature for nearly an hour to facilitate grain growth and was etched deeply in alcoholic nitric acid before photographing. This structure is wholly sorbite, no pearlite, nor free ferrite can be detected. The long time treatment has served to coarsen the structure and to cause a grain-like appearance. The Brinell hardness of this specimen was 229.

It is quite evident from these three illustrations that sorbite may vary widely in appearance and in composition. In a steel containing 0.35 per cent carbon, we may have a little free ferrite present. We may, and frequently do, have granular pearlite and sorbite occurring together, and so nearly alike in appearance that it is almost impossible to tell one from the other. The formation of sorbite depends on many factors, the most important of which are speed of cooling and the chemical composition. It is evident that in some alloy steels containing but 0.35 per cent carbon (Fig. 48) we may have a structure consisting wholly of sorbite; on the other hand, in other alloy steels or in plain carbon steels, there will be so much free ferrite present that some of it will be evident with the microscope.

In order to be sure of identifying sorbite with the microscope we should know something of the chemical composition, the heat treatment accorded to the material, and its Brinell hardness. As we shall see in a few moments, it is relatively easy to distinguish

⁴²Speaking accurately it is not correct to say that sorbite, troostite or martensite are fine-grained or coarse-grained. In most structures of these three constituents unless drastically overheated they have no visible grain boundaries. Compared with a typical ferrite structure, heat treated steels have no well-defined grains, as a rule. It has become customary, however, to speak of a structure as fine-grained or coarse-grained from the general size and distribution of the individual particles; so according to this somewhat inaccurate nomenclature Fig. 47 is fine-grained and Fig. 48 is coarse-grained sorbite.

sorbite from granular pearlite compared with the difficulty of identifying it when associated with troostite.

THE STRUCTURE OF MARTENSITE

Before viewing the structure of troostite, the transition constituent coming between martensite and sorbite, it is advisable first to become familiar with the structure of martensite. Of the three constituents that we are describing, martensite has the most characteristic and uniform appearance when viewed by the microscope. Sorbite, being closely related to granular pearlite, ranks next, and troostite is the most variable in appearance and the hardest to identify positively with the microscope, especially when associated with sorbite.

Martensite is ordinarily formed when steel containing between 0.65 and 1.25 per cent carbon is quenched from above the A_{r1} point in cold water. If the steel is small in cross section the structure will be practically all martensite.⁴³ This is the case with small tools, less than one inch in cross section. When martensite is formed by drastic quenching in steels containing less than 0.50 per cent carbon there is frequently some free ferrite present, especially so in the low carbon grades. In very high carbon steels, above 1.25 per cent, or in some alloy steels, particles of free cementite or other carbides can often be detected in the microstructure.

In general, martensite in quenched high carbon steels appears as a needle-like structure of which Fig. 49 is typical. This specimen was taken from a half inch bar of tool steel containing 1.10 per cent carbon quenched from 1650 degrees Fahr. in cold water. The same specimen at much higher magnification is shown in Fig. 50. The acicular structure is plainly evident. The Brinell hardness of the specimen shown in Fig. 49 and 50 was 654. Steel of approximately the same composition quenched from 1400 degrees Fahr. in cold water is shown in Fig. 51. This bar was $\frac{3}{4}$ inch in diameter and the area photographed as Fig. 51 was near the center. There is no doubt but that the martensite shown in Fig. 51 contains some troostite as the Brinell hardness was 514 as compared with 654 for Fig. 49 and 50.

Other structures of martensite are shown in Fig. 52, 53 and

⁴³As we shall see in a subsequent installment, martensite in hardened steels seldom is pure. Hardened steel is usually an aggregate consisting principally of martensite, but probably containing some austenite and troostite.

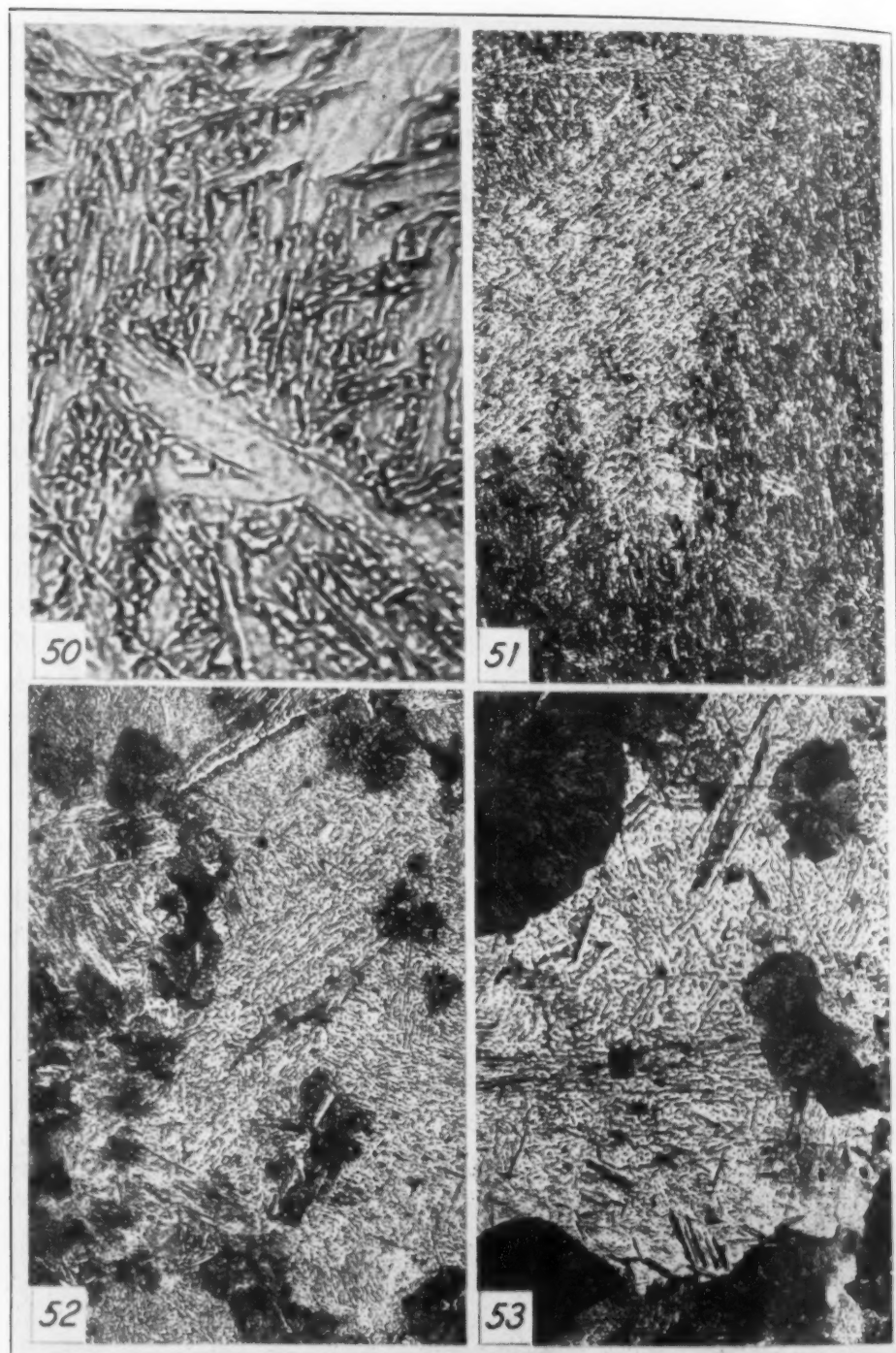


Fig. 50—Photomicrograph Showing Typical Martensite Structure at High Magnification. $\times 3000$. Fig. 51—Photomicrograph Showing Fined Grained Martensite Possibly Contaminated by Troostite. Brinell Hardness 514. $\times 500$. Fig. 52—Photomicrograph Showing Troostite Forming at the Boundaries of Martensite Grains. $\times 500$. Fig. 53—Photomicrograph Showing Troostite Forming at Grain Boundaries and Within the Martensite Grains. $\times 500$.

54. In these three specimens the needle-like structure of the ground-mass is characteristic.

THE STRUCTURE OF TROOSTITE

The structure of troostite results from cooling at a rate faster than that necessary to produce sorbite but slower than the critical cooling rate when martensite is formed. As we shall see in a later installment the simplest way to produce a structure consisting wholly of troostite is to quench to form martensite and then temper at about 750 degrees Fahr. (400 degrees Cent.). We can also regulate the cooling rate in such a way that the Ar_1 point is depressed to 1100 to 1200 degrees Fahr. (600 to 650 degrees Cent.). This can frequently be accomplished by quenching small pieces of high carbon tool steel from above the Ar_1 point in oil.

To examine the structure of troostite in its most characteristic form, the simplest method of preparing the specimen is as follows. Heat a relatively large bar—for example, $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter—of high carbon tool steel to about 1600 degrees Fahr. (about 200 degrees above Ar_1) and quench in cold water. A transverse section of such a bar will have a martensitic structure near the edge where the cooling rate was the most rapid; a short distance from the surface the cooling rate will be such that troostite is just beginning to form. A little further towards the center the structure will be all troostite and near the center of the bar the structure will probably be sorbite or even pearlite.

This method of preparation was used for the specimens shown in Fig. 52, 53 and 54, except that the bar was heated to 1900 degrees Fahr. in order to promote the growth of large grains. Fig. 52 shows the structure of an area about $\frac{1}{4}$ inch from the surface of the quenched bar. The grains are martensite with troostite beginning to form at the grain boundaries. Just adjacent to the area shown in Fig. 52 was the area photographed as Fig. 53. The dark troostite occupies a much greater area than in Fig. 52 and the formation of this constituent within the grains is shown.

The appearance of troostite is shown in detail in Fig. 54. This is the same specimen and in approximately the same location as that shown in Fig. 52 but at 2000 diameters. At this magnification the duplex character of the troostite is evident. It is not possible to state whether the light colored particles within the

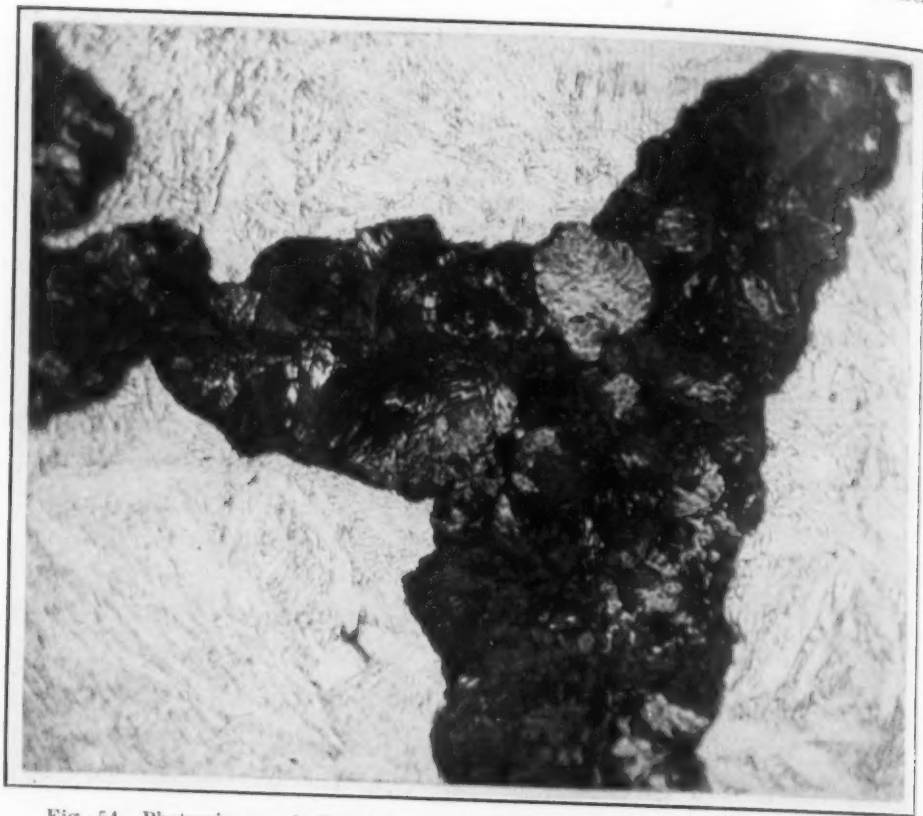


Fig. 54—Photomicrograph Showing Complex Structure of Troostite at High Magnification.
× 2000.

dark areas clearly evident in Fig. 54 are actually troostite or not. Fig. 54 shows clearly how troostite forms at the boundaries. The troostite shown in Fig. 54 has formed at the junction of three grains of martensite; the grain boundaries can be detected running to a common junction directly through the center of each extending arm of troostite.

It is quite easy to detect troostite when associated with martensite due to the difference in etching characteristics. Troostite etches much more rapidly and is stained much darker than martensite, as is evident from Figs. 52, 53 and 54. This serves to distinguish with certainty any troostite that has formed under the same conditions as illustrated in these three photographs. When martensite is formed by quenching and troostite formed by reheating or tempering this martensite, it is much more difficult to identify it positively. Fig. 55 shows such a structure. This specimen was taken from a half inch bar of high carbon tool steel quenched from 1500 degrees Fahr. in water and tempered at 800

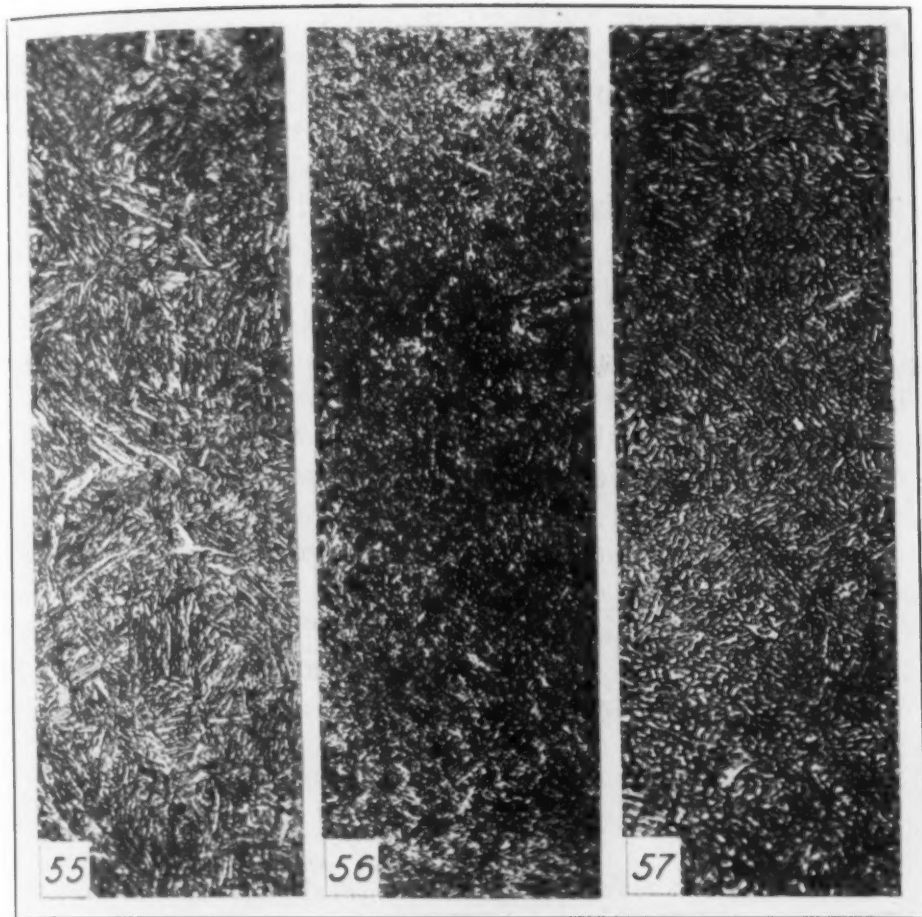


Fig. 55—Photomicrograph Showing Troostite in Tempered Carbon Tool Steel. Brinell Hardness 346. $\times 500$. Fig. 56—Photomicrograph Showing Troostite in Tempered Nickel-Chromium Steel. Brinell Hardness 352. $\times 500$. Fig. 57—Photomicrograph Showing Troostite in Tempered Nickel-Chromium Steel. Brinell Hardness 363. $\times 500$.

degrees Fahr. The Brinell hardness was 346. Theoretically this structure should be all troostite. From the heat treatment and the resulting hardness we are reasonably sure this structure is troostite but if we had only the metallographic structure shown in Fig. 55 and did not know the composition, the heat treatment or the hardness we could not be so positive.

Figs. 56 and 57 are specimens taken from gears of 0.40 per cent carbon, 2.00 per cent nickel, 1.00 per cent chromium, quenched in oil and tempered at 850 to 900 degrees Fahr. The Brinell hardness of these two specimens is 352 and 363. Theoretically these two structures should be troostite.

Now compare Figs. 55, 56 and 57 with Fig. 47, sorbite, and

Fig. 51 which is presumably martensite. The great similarity between these structures is plain. Yet the steel shown in Fig. 47 which is probably all sorbite had a Brinell hardness of 235 and the steel shown in Fig. 51 which is fine-grained martensite possibly contaminated by a little troostite had a Brinell hardness of 514. The troostite steels, Figs. 55, 56 and 57 had, as we saw, hardness values of 346 to 363.

It is quite evident that unless troostite forms under such conditions that it is associated with martensite as shown in Figs. 52 and 53, it is very difficult to tell by microscopic examination alone whether the structure is a fine-grained sorbite, a fine-grained martensite or troostite, and doubly difficult when one constituent occurs in conjunction with another in the same specimen. In heat treated steels containing considerable carbon, alloys, or both, we may have in the structure, martensite, troosto-martensite, troostite, troosto-sorbite, sorbite, or granular pearlite. It is difficult to identify these various transition constituents definitely by microscopic examination alone; in order to be positive we should know the composition, the heat treatment given to the material, and in any case the hardness.

SUMMARY

From the discussion in this and the preceding chapter we should be familiar with the characteristics of sorbite, troostite and martensite, the three transition constituents occurring in heat treated carbon and alloy steels. One of the important things to remember in connection with these three transition constituents is that they represent a structural condition that is more or less unstable.

The normal structural change in cooling an iron-carbon alloy from above the A_{r1} point to atmospheric temperature is a change primarily from the solid solution austenite, stable above A_{r1} to the aggregate pearlite, stable below A_{r1} . With extremely fast cooling, martensite, the most unstable constituent is formed. Slightly slower cooling results in the formation of troostite and still slower cooling in the formation of sorbite. Troostite is a more stable structural condition than martensite, but less stable than sorbite, and sorbite is less stable than pearlite.

Martensite, the most unstable structural condition is, of course,

the hardest and strongest of the constituents and at the same time the most brittle. Troostite is less strong and hard and more ductile than martensite and at the same time more stable in structure. Sorbite, still more stable than troostite is less strong and hard and more ductile; and pearlite the stable structural condition of an iron-carbon alloy below A_{r1} is the weakest, softest and most ductile.

From this it is evident that heat treating a steel to obtain maximum hardness results in the most unstable structural condition. If this is the case it is plain that the steel will tend to return to a more stable structural condition at the first opportunity, and that this return to stable equilibrium is accompanied by a decided reduction in hardness and strength. These facts are the basis for the theories of hardening and tempering to be discussed in subsequent installments.

In examining heat treated steel with the microscope it must be remembered that martensite, troostite and sorbite represent a transition in structure from austenite to pearlite and as they are not definite in composition and in the way they are formed, they will not be constant in appearance. The martensite formed by quenching a steel containing 1.25 per cent carbon will be different in constitution than that formed in quenching a steel containing 0.75 per cent carbon. Under the microscope these two structures may or may not look alike. The martensite formed by quenching a 1.00 per cent carbon steel from 1400 degrees Fahr. may look very different from the martensite formed by quenching from 1800 degrees.

In addition, if the martensite in a high carbon steel contains some troostite as evidenced by a lower hardness, it may or may not resemble exactly the martensite that contains little or no troostite. And not only may some martensitic structures look very different from other martensitic structures but in addition martensite may resemble troostite and likewise troostite may resemble sorbite.

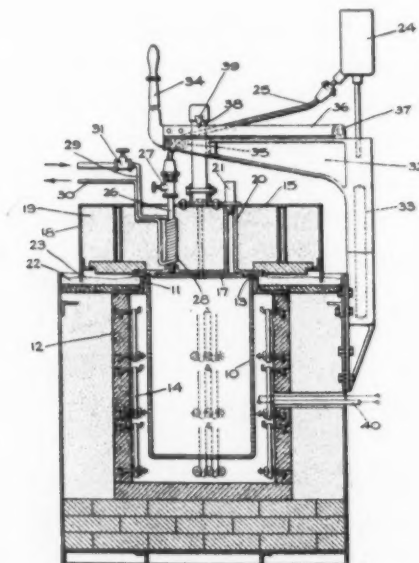
The point brought out, and illustrated in the foregoing pages is that in order to identify martensite, troostite and sorbite with certainty we must take other factors into consideration besides the general appearance of the structure; we should know the heat treatment if possible, the chemical composition of the steel and in any case its hardness or strength.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,696,603, Dec. 25, 1928, Carburization of Metals, George W. Hegel, of Schenectady, N. Y. and Gerald R. Brophy, of Niskayuna, N. Y., Assignors to General Electric Company, a corporation of New York.

This patent describes a method and apparatus for case carburization by the use of vapors of a carbon containing liquid. The apparatus comprises a retort 10 which is set into the heating chamber heated by the resistance elements 14 and into which the materials to be case hardened are placed. The top of the retort 10 is sealed by a cover 15 having a flange

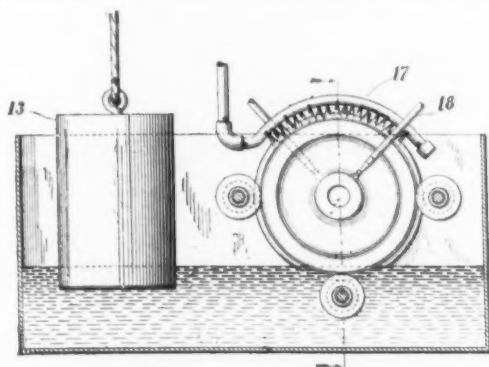


23 imbedded in the sand seal 22. The carbon-containing liquid which may be a petroleum product, or turpentine, or linseed oil and the like, is introduced into the retort 10 through the pipe 26 fed from the tank 24. The pipe 26 is water cooled by the circulating coil 28 which prevents vaporization of the oil in the pipe and prevents the formation of carbon which might otherwise clog the flow through the pipe 26. The pipe 20 provides a vent to permit slow escape of the vapors formed in the retort 10, the escape of gas from the nozzle 21 indicating that the pressure in the retort 10 is sufficient to prevent the entrance of air into the retort. The patent states and claims that liquids containing carbon but lacking in oxygen are not good carburizing materials, and that these liquids should be energized by the introduction of energizers containing oxygen and pref-

erably nitrogen. Bone oil and nitrobenzene mixed with kerosene makes a very active carburizing atmosphere.

1,697,068, Jan. 1, 1929, Manufacture of Irregular-Shaped Objects, Edward F. Kenney, of Bethlehem, Pa.

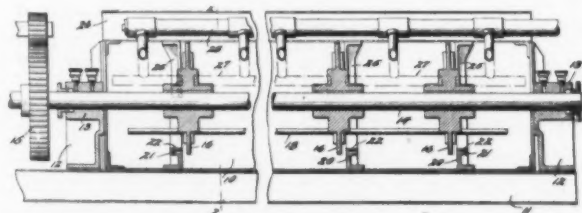
This patent describes the manufacture of an irregular shaped article, such as car wheels, which, while the forging is still hot, are subjected to a cooling action to chill the heavy sections such as the rim and the hub, without subjecting the thin flange to rapid cooling which might



set up dangerous cooling strains. The heated car wheel coming from the forging dies is placed on the three rotating rollers and rapidly rotated while the lower portion of the flange is immersed in the liquid in the tank, and the upper portion of the flange is subjected to a spray from the nozzle 17 and the hub subjected to a spray from the nozzle 18. As soon as the wheel is quenched in this way, the temperature is equalized in a soaking pit above the blue heating zone but below the critical range and then cooled to atmospheric temperature.

1,696,806, Dec. 25, 1928, Device for Treating Rods, Charles E. Lehr, of Bethlehem, Pa., assignor to Bethlehem Steel Company, of Bethlehem, Pa., a corporation of Pennsylvania.

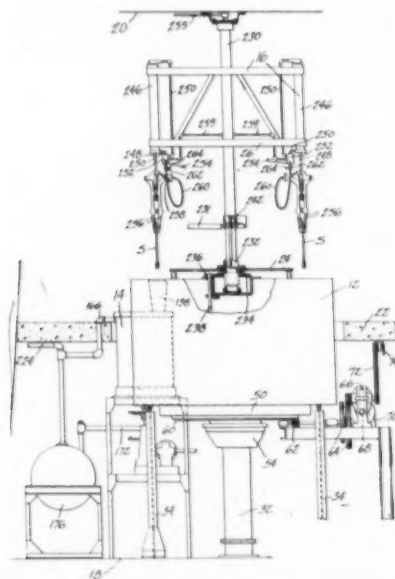
This patent describes an apparatus for continuously treating rods 18 which may be fed down the chute 23 and are held in notches 17 in the



revolving disks 16 and rotated along the wearing members 22 through the tank 10. At the point of entrance into the tank, the rods are sprayed with liquid from the nozzles 27 and 29 to quench the same, and as the rods emerge from the vat 10, the stationary arms 25 lift the rods from the notch 17 and discharge them on to the platform 24.

1,697,820, Jan. 1, 1929, Harry O. Lang and John McGeorge, of Pontiac, Michigan, Assignors to General Motors Corporation, of Detroit, Michigan, a corporation of Delaware.

This patent describes a revolving turret heat treating apparatus in which shafts, such as axles and the driving connection between the differential and the rear wheels of an automobile, may be treated and may be



maintained in a vertical position to prevent warping. The shafts S are handled by gripping tongs 256 and are placed in and removed from the hardening and drawing furnace 12 and the quenching tank 14 as these members rotate on the turret.

1,695,337 and 1,695,338, Dec. 18, 1928, Carburizer, Frederick C. Langenberg, of Watertown, Mass., assignor to E. F. Houghton & Company, of Philadelphia, Pa., a corporation of Pennsylvania.

These patents describe a new type of energizing material for case hardening compounds and a new carburizer or case hardener. In the first patent, the energizing material described and claimed consists of an oxygen containing salt of an alkaline earth metal and a salt of an alkaline metal having nitrogen and oxygen in the acid radical. Specifically, the energizing materials may be barium carbonate, calcium acetate and potassium nitrite. In the second patent, the new material may be a cobalt salt of an organic acid, such as cobalt acetate and also barium carbonate.

1,695,430, Dec. 18, 1928, Agent for Cleaning and Imparting Rust-Inhibitive Properties to Steel, James D. Klinger, of Detroit, Michigan.

This patent describes a cleaning and rust-proofing composition comprising alcohol, citric acid, sulphuric acid and acetone. The material may be painted or sprayed upon the metal and permitted to act for two or three minutes and then removed by rinsing with hot or cold water.

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THE ENGINEERING INDEX

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ALLOY STEELS

COPPER CONTENT. Cuprous Steels with High Carbon Content (Kupferstaehle mit hohem Kohlenstoffgehalt), A. F. Stogoff and W. S. Messkin. *Archiv fuer das Eisenhuettenwesen* (Duesseldorf), vol. 2, no. 5, Nov. 1928, pp. 321-331, 22 figs.

Results of dilatometric and thermal investigations and determination of electric conductivity; investigation of structure; magnetic properties and strength of cuprous steels. Bibliography.

TEMPERATURE EFFECT. Chrome-Tungsten Steel Excellent at High Temperatures, A. E. White and C. L. Clark. *Iron Age*, vol. 122, no. 25, Dec. 20, 1928, pp. 1556 and 1616.

Report on effect of alloying elements upon stability of steel at elevated temperatures discussed; results of tests with heat-treated chrome-tungsten steel tested at 1000 deg. Fahr.; such steel not easy to machine or fabricate but believed to be promising for high-temperature high-pressure work.

ALUMINUM

PROPERTIES. Influence of Composition and Cold Working on Corrosion and Increase of Grain Size of Aluminum (Influence de la composition et de l'écrouissage sur la corrosion et le grossissement du grain de l'aluminium), L. Guillet and Ballay. *Academie des Sciences-Comptes Rendus (Paris)*, vol. 187, no. 15, Oct. 8, 1928, pp. 585-587.

Pure aluminum corrodes less than if only 98.81 per cent pure in aqueous hydrochloric acid, pure nitric acid, and 3 per cent sodium-chloride solution; both metals behave alike in 5 per cent nitric-acid and sulphuric-acid solutions; influence of cold working is much

greater in case of impure aluminum, both in increasing corrosion and enlarging grain size.

ALUMINUM ALLOYS

TESTING. Production of So-Called "Y" Alloys (Versuche ueber die zweckmaessigste Herstellung der sog. "Y"-Legierung), W. Claus and E. Kalaehne. *Giesserei* (Duesseldorf), vol. 15, no. 48, Nov. 30, 1928, pp. 1200-1203, 3 figs.

These alloys consist of 1.5 per cent magnesium, 2 per cent nickel, 4 per cent copper, and 92.5 per cent aluminum, and belong to group of light alloys, especially to that group which can be annealed in cast state; results of tests with these alloys.

ALUMINUM PLATE VS. TIN

Has Tin Plate a New Competitor? C. L. Mantell. *Iron Age*, vol. 122, no. 25, Dec. 20, 1928, pp. 1555-1556.

Employment of aluminum plate as substitute for tin plate investigated in Germany; influence of aluminum of 99 to 99.5 per cent purity on preserved food; Germans planning to erect plants; aluminum-coated sheets light; technology of coating process; tin and aluminum coatings compared; question of their achieving popularity.

BLAST FURNACE GAS

GERMANY. The Use of Gas in German Iron and Steel Works, Bansen. *Iron and Coal Trades Rev. (Lond.)*, vol. 117, no. 3165, Oct. 26, 1928, pp. 616-617, 2 figs.

Heating furnaces; various heating contrivances; gas supply and requirements; gas production and utilization policy; qualifications of furnace worker; boilers for using surplus gas; calculations of production costs.

Those members who are making a practice of clipping items for filing in their own filing system may obtain extra copies of the Engineering Index pages gratis by addressing their request to the society headquarters, whereby their names will be placed on a mailing list to receive extra copies regularly.

Paper read before World Power Fuel Conference.

BLAST FURNACES

DOVEL TYPE. Dovel Type Blast Furnace Put on Test, J. P. Dovel. *Blast Furnace and Steel Plant*, vol. 16, no. 12, Dec. 1928, pp. 1555-1558 and 1570, 2 figs.

Design and operation of improved Dovel-type blast furnace, with double skip-filled McKee top and stack equipped with nine rows of Dovel inwall cooling blocks, principal object of design being to production of flue and steel plants is operated for six days on burden of crushed ore; procedure stimulates northern practice; results of test are given.

DISINTEGRATION. Studies of Disintegration of Blast-Furnace Bricks by Carbon Monoxide (Untersuchungen ueber die Zersetzung von Hochofensteinen durch Kohlenoxyd), E. Diepschlag und K. Feist. *Festung (Leipzig)*, no. 9, Sept. 1928, pp. 133-136.

Review of theories and literature on subject; critical analysis of suggested causes; experimental tests of theories.

BLOOMING MILLS

TRANSFER TABLES. Chain Transfer Tables for Blooms. *Blast Furnace and Steel Plant*, vol. 16, no. 12, Dec. 1928, pp. 1559 and 1570, 3 figs.

Routing from shear to four distinct operations accomplished at new plant of Timken Steel and Tube Co. by chain transfer tables, thus allowing special treatments necessary in production of alloy-steel blooms in quantity; design of transfer table and operating control are discussed.

BOILER PLATES

MANUFACTURE. Making Large Plates of Alloy Steel, C. McKnight and W. G. Hump-ton. *Iron Age*, vol. 122, no. 24, Dec. 13, 1928, pp. 1492-1494, 4 figs.

Manufacture of steel plates for locomotive boilers is described; steels having nickel between 2 and 3 per cent without other alloying elements, manufactured into large plates between $\frac{1}{4}$ and $1\frac{1}{2}$ in. thick; practices applicable to other alloy steels and other sizes; splashing during teeming and chilling during stripping are avoided; chipped slabs cleaned of scale in rolling process; flattening and heat treating; testing. Abstract of paper presented before Am. Soc. Mech. Engrs.

BRASS

NICKEL. Nickel Brasses, A. C. Sturkey. *Metal Industry (Lond.)*, vol. 33, no. 21, and 22, Nov. 23 and 30, 1928, pp. 485-488 and 494, and 521, 2 figs.

Brief description of graphical method by which properties of ternary system of nickel brasses are best represented; copper-zinc effects of impurities and suggestions concerning foundry practice; pouring temperature; nickel high-tensile brasses; quaternary nickel bronzes, known principally as manganese bronzes; properties of chill-cast specimens. Bibliography. Paper read before Scottish Local Sections of Inst. of Metals.

CADMIUM PLATING

Cadmium coating (le cadmiage), G. de

Lattre. *Revue de Metallurgie (Paris)*, vol. 25, no. 11, Nov. 1928, pp. 630-636, 5 figs. Discussion of cadmium deposition and its advantages; comparison with zinc and tin; chemical resistance to acids; disadvantages of cadmium; preparation of zinc-cadmium alloy.

CASE HARDENING

CYANIDE. New Salt Bath Hardening Process. *Machy. (Lond.)*, vol. 33, no. 842, Nov. 29, 1928, p. 267, 2 figs.

Details of bath hardening medium composed of sodium cyanide and various other ingredients which act as accelerators, called Durrferite cyanide hardening flux; practice recommended; articles after hardening possess very smooth clean surface.

CYANIDE. The Deterioration of the Cyanide Bath, V. E. Hillman and E. D. Clark. *Black and White (Metal Sec.)*, vol. 1, no. 5, Oct. 1928, pp. 27-29, 1 fig.

Rate of deterioration is not constant or uniform; impoverished bath will develop case only 1 to 3 thousandths in depth; bath maintained with proper concentration of sodium cyanide will produce case of 6 to 8 thousandths in depth.

MATERIALS. Evaluation of Case-Hardening Materials (Zur Untersuchung und Bewertung von Ersatzhaertemitteln), F. Hebler. *Chemiker-Zeit. (Koethen)*, vol. 52, no. 79, Oct. 3, 1928, pp. 775-776.

For temporary case-hardening of iron, no better results are obtained with wood charcoal than with other carbonaceous materials, such as coke, lignite, etc.; degree of case-hardening is scarcely affected by addition of chalk to carbon, but progressive increase in thickness of hardened layer is obtained by use of carbonates of sodium, strontium, and barium.

NITRATION. The Case-Hardening of Steels by Nitrogen. *Engineer (Lond.)*, vol. 146, no. 3804, Dec. 7, 1928, pp. 637-638, 4 figs.

Particulars giving brief description of nitration process, which is invention of Fry of Fried, Krupp Co., Essen; effect of nitrogen on steels; surface hardness produced by nitration; nitralloy special steels; working of nitralloy steels; advantages of process.

CASTINGS

CLEANING. Cleaning Room Progress Aids Production of Quality Castings, F. G. Steinbach. *Foundry*, vol. 56, no. 23, Dec. 1, 1928, pp. 987-989, 8 figs.

Cleaning-room conveyors are described; applications of roller conveyors; few power conveyors applicable to foundry cleaning room; hand and lift trucks for transporting castings; electric and gasoline tractor; loaders for sand-blast equipments. (Continuation of serial.)

INTERNAL STRESSES. Internal Stresses, A. Le Thomas. *Foundry Trade Jt. (Lond.)*, vol. 39, no. 642, Dec. 6, 1928, pp. 414-415, 2 figs.

Suppression of internal stresses in castings; table given shows results obtained on rough-cast test pieces reheated to different temperatures, with corresponding shearing test values and Brinell hardness; responsibility incurred by founder in regard to stresses causing apparently spontaneous rupture. Paper presented to Paris Foundry Congress.

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CAST IRON

CORROSION. Corrosion and Rusting of Cast Iron With and Without Alloys (Ueber die Korrosion und das Rosten von unlegiertem und legiertem Gusseisen), P. Koetzschke and E. Piwowarsky. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 5, Nov. 1928, pp. 333-340, 25 figs.

Influence of nature of graphite formation and small additions of nickel, chromium, and copper on corrosion in acids and rusting in aqueous solutions; corrosion in strong brines; weather resistance of cupric cast iron.

DEOXIDATION. Mechanical Properties of Deoxidized Cast Iron (Die mechanischen Eigenschaften von desoxydiertem Gusseisen), P. Bardenheuer and K. L. Zeyen. *Giesserei (Duesseldorf)*, vol. 15, no. 45, Nov. 9, 1928, pp. 1124-1128.

Review of literature on role of oxygen in cast iron; tests to determine influence of deoxidation of cast iron with ferrotitanium on mechanical properties of sand-cast and annealed chill-cast iron; influence of sulphur and phosphorus on properties of deoxidized cast iron. Bibliography.

EUTECTIC. Eutectic Cast Iron, A. Mitinski. *Foundry Trade JI. (Lond.)*, vol. 39, no. 642, Dec. 6, 1928, p. 413.

Author believes that at no distant date hyper-eutectic cast iron would disappear and that electric furnace, by eliminating ferric oxide and germs of primary graphite, while increasing fluidity of metal, would enable silicon and phosphorus contents to be reduced. Paper presented to Paris Foundry Congress.

GRAPHITIZATION. London Metallurgists Criticise German Research Work on Cast Iron. *Foundry Trade JI. (Lond.)*, vol. 39, no. 643, Dec. 13, 1928, pp. 433-435.

Further criticism of paper entitled Graphite in Gray Cast Iron and Its Influence Upon the Mechanical Properties, by P. Bardenheuer and K. L. Zeyen, published in Aug. 23 issue of Journal; underlying principles for research on cast iron; question as to whether graphite exists in molten cast iron; chill-cast pig iron as ameliorative; high-strength ferrite graphite irons; chill cast iron available; graphite not found in liquid centrifugally cast iron.

GROWTH. Growth of Gray Cast Iron with Special Regard to Nickel and Chromium (Beitraege zum Wachsen von grauem Gusseisen unter Beruecksichtigung der Elemente Nickel und Chrom), E. Piwowarsky and W. Freytag. *Giesserei (Duesseldorf)*, vol. 15, no. 48, Nov. 30, 1928, pp. 1194-1200, 13 figs.

Character and significance of growth are discussed; investigations of influence of nickel and chromium, and of different alloying elements on growth; influence of graphitization, density, gas content, and jolting process; relation between growth and change in gravity when annealing with air admission.

IMPROVEMENT. Improvement of Cast Iron (Sur l'amelioration des fontes de deuxième fusion), L. J. Gouttier. *Fonderie Moderne (Paris)*, vol. 22, Nov. 10, 1928, pp. 427-433, 5 figs.

Description of Walter process; special arrangements, applications and economy of process; advantage of desulphurization.

IMPROVEMENT. A Consideration of the Various Claims for Producing High-class

Cast Iron, H. J. Young. *Foundry Trade JI. (Lond.)*, vol. 39, no. 642, Dec. 6, 1928, pp. 408-410, 1 fig.

Production of high-class cast iron allied to that of waster castings because where cast iron must be genuinely high-class, it becomes imperative to scrap good casting when its metal is not true to type; specifications inadequate; chaotic situation carbon variations; Diesel-engine cylinders.

CHROMIUM ALLOYS

Chromium Alloys, F. M. Becket. *Min. and Met.*, vol. 9, no. 264, Dec. 1928, pp. 551-554.

Introduction, dealing briefly with history of discovery of chromium and its alloys. (To be continued.)

COPPER

ANNEALING. Annealing Copper Parts. *Mech. World (Manchester)*, vol. 84, no. 2187, Nov. 30, 1928, pp. 507-508, 1 fig.

By controlling annealing temperatures, limiting cold work to below critical point, and examining metal surface cold-worked after annealing, copper articles may be produced in condition of physical soundness; regulation of time and temperature of annealing will promote greater workability of metal.

CORROSION INHIBITORS. Effect of Inhibitors on the Acid Solution of Copper and Copper Alloys, H. O. Forest, J. K. Roberts and B. E. Roetheli. *Indus. and Eng. Chem.*, vol. 20, no. 12, Dec. 1928, pp. 1369-1371, 11 figs.

Addition of inhibitor materials greatly diminishes corrosion of copper and copper alloys in concentrated hydrochloric acid; in more dilute acids effect of inhibitors is not so marked; effects support belief that mechanism of protective action of inhibitor materials is deposition of adsorbed layer of inhibitor or substance formed from inhibitor which decreases area effective for depolarization.

COPPER INGOTS

MOLDS. Water-Cooled Copper Molds, W. Rohn. *Metallurgist (Supp. to Engineer, Lond.)*, Nov. 30, 1928, pp. 169-170.

Notes on casting alloys of iron and nickel at very high temperatures in vacuum; relying upon marked differences between steel and copper under water cooling, all-copper water-cooled mold was constructed out of piece of thick-walled copper tube, on outer side of which deep spiral groove was machined; molds of this form have been successfully used for long time and promise to have practically indefinite life. Abstract translated from Zeit. fuer Metallkunde, Dec. 1927.

COPPER-ZINC ALLOYS

METALLOGRAPHY. Transformations of the Beta-Phase in the Copper-Zinc System (Verwandlungen der Beta-Phase im System Kupfer-Zink), P. Saldau and I. Schmidt. *Zeit. fuer anorganische u. allgemeine Chemie (Leipzig)*, vol. 173, no. 3-4, July 23, 1928, pp. 273-286, 5 figs.

Boundaries of Beta-phase in copper-zinc alloys were determined by tempering at various temperatures for 84 days followed by quenching and examination of microstructure; dis-

crepancies found by previous workers in limiting compositions of Beta field are ascribed to insufficient time of annealing to obtain equilibrium being used in their work.

CORROSION

Corrosion Phenomena (Ueber Korrosionerscheinungen) A. Thiel. *Korrosion und Metallschutz (Berlin)*, vol. 4, no. 8, Aug. 1928, pp. 177-178.

Fifteenth report from Physico-Chemical Institute of University of Marburg; discussion of relation between results of Darmstadt and Marburg experiments.

TESTING. Method of Testing Corrosion Intensity with Aid of Indicators (Methoden zur Pruefung der Korrosion mit Hilfe von Indikatoren), H. Thiele. *Korrosion und Metallschutz (Berlin)*, vol. 4, no. 7, July, 1928, pp. 152-153.

Report from Prussian Institute of Water, Soil and Air Hygiene on use of Cushman ferroxyd and other indicators for determination of inequalities of corrosion intensity on surfaces of non-ferrous metal parts, particularly aluminum.

CUPOLAS

CHARGING. Charging Cupolas Mechanically, J. A. Murphy. *Foundry*, vol. 56, no. 24, Dec. 15, 1928, pp. 1023-1024, 4 figs.

Laying out yard and charging equipment; materials carried in charging buckets from ground-level storage direct to cupolas; travelling scale car equipped with multi-beam scale; gravity storage bins; in small foundries scale car employed without use of gravity bins.

DESIGN. The Calculation of the Useful Height of a Foundry Cupola, M. Karnaoukhov. *Iron and Steel Industry (Lond.)*, vol. 2, no. 3, Dec. 1928, pp. 83-85.

Important theoretical considerations involved in cupola design; new method of calculation of useful height of cupola based on nature of heat distribution within cupola; sensible heat losses calculated; general heat balance during four hours of work; formula constant when working conditions remain constant; advantages and disadvantages of increasing cupola height.

OPERATION. Operation of Cupola with Hot Blast Increases Operating Economy, F. K. Vial. *Fuels and Furnaces*, vol. 6, no. 12, Dec. 1928, pp. 1667-1670 and 1690.

Discussion of savings which may be effected by operation of cupolas with hot blast; experimental hot-blast cupola and results obtained. Abstract of paper presented before Am. Soc. Mech. Engrs.

ELECTRIC FURNACES

Electric Furnaces for Calcium Carbide and Ferro-Alloys, J. White. *S. African Inst. Elec. Engrs.—Trans. (Johannesburg)*, vol. 19, no. 10, Oct. 1928, pp. 198-207, 4 figs.

Object of this paper is to describe in detail present methods of producing calcium carbide and ferroalloys by means of electric furnaces; three-phase furnaces; continuous electrodes.

INDUCTION. Induction Heating of a Cylinder full of Pure Copper (Le chauffage par induction d'un cylindre plein de cuivre rouge), M. Mathieu. *Arts et Métiers (Paris)*,

vol. 81, no. 98, Nov. 1928, pp. 410-414, 5 figs.

Statement of problem and difference between this problem and that of induction furnace with hollow conductor; determination of effective resistance and variation of power factor in functions of temperature.

MELTING. Melting Brass in the Electric Furnace, J. L. Faden. *Indus. Power*, vol. 15, no. 6, Dec. 1928, pp. 159-163, 2 figs.

Types of electric melting furnaces in commercial use are induction and rocking-arc furnaces; two operating cost schedules are given for induction furnace; daily chart of performance of rocking-arc electric furnace in foundry producing plumbers' cast-brass goods.

RESISTANT. Industrial Electric Heating, N. R. Stansel. *Gen. Elec. Rev.*, vol. 31, no. 12, Dec. 1928, pp. 662-672, 26 figs.

Desirable properties of material for resistor are summarized; materials in common use for furnace resistors; use of molybdenum as material for furnace resistors; insulation of resistor circuit in furnace; shapes of resistor elements. (Continuation of serial.)

ELECTRIC WELDING

RESISTANCE. Welding Low-Resistance Metals, P. T. Van Bibber. *Am. Mach.*, vol. 69, no. 24, Dec. 13, 1928, p. 925.

Difficulties in electric resistance welding of copper, brass, silver, and platinum; heating effect controlled to considerable degree by resistance of joints and this accounts for variation in quality of welding of pieces identical in shape; variation in power-line voltage also serious drawback; with some commercial spot welders modifications in transformer necessary.

FURNACES

ANNEALING—NORMALIZING. Modern Furnaces for Normalizing Sheets, *Blast Furnace and Steel Plant*, vol. 16, no. 12, Dec. 1928, pp. 1571-1573 and 1578, 4 figs.

Description given of equipment lately installed for continuous annealing of sheet steel; metallurgical features are fully discussed; furnace 155 ft. long and divided into preheat, soaking, and cooling zones; oil burned through inducing burners with steam under high pressure as atomizing agent; auxiliary set of gas burners; thermal and structural changes as sheets progress through furnace.

HEAT TREATING, GAS FIRED. Furnaces As Production Equipment, E. G. de Coriolis. *Machy. (N.Y.)*, vol. 35, no. 4, Dec. 1928, pp. 273-274, 2 figs.

Heat-treating furnaces as important links in production equipment; essential factors in designing automatic gas furnace.

MELTING—PULVERIZED COAL. Significance of the Brackelsberg Furnace for the Iron Foundry, Especially in Production of High-Grade Cast Iron (Die Bedeutung des Brackelsberg-Ofens fuer die Eisengiesserei), P. Bardenheuer. *Giesserei (Duesseldorf)*, vol. 15, no. 47, Nov. 23, 1928, pp. 1169-1173, 5 figs.

MELTING—PULVERIZED COAL. Brackelsberg Rotary Furnace for Melting Cast Iron and Malleable Castings (Der Brackelsberg-Drehofen zum Schmelzen von Gusseisen und Temperguss), P. Bardenheuer. *Giesserei*

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(Düsseldorff), vol. 15, no. 33, Aug. 17, 1928, pp. 814-815 and (discussion) 816, 2 figs.

Furnace consists of ingot-steel drum mounted on rolls, and is fired with pulverized coal; advantages of this melting process, which are principally of metallurgical nature, are enumerated, and results of tests given.

METALLURGICAL—GAS FIRING. Use of Gas in the Heavy Industries (Die Anwendung des Gases in der Grossindustrie), Jehnigen. *Gas- und Wasserfach (Munich)*, vol. 71, no. 45, Nov. 10, 1928, pp. 1090-1095, 19 figs.

Design of gas furnaces and heat-treating equipment of iron and steel works, wire-drawing plants, etc.

HARDNESS TESTS

BRINELL. Behavior of Metal Under the Brinell Test, A. L. Norbury and T. Samuel. *Heat Treating and Forging*, vol. 14, no. 12, Dec. 1928, pp. 1422-1426, 2 figs.

Paper presented before Brit. Iron and Steel Inst., previously indexed.

IMPACT TESTING

NOTCHED BAR. On the Relation Between Stress and Strain in the Impact Test. R. Yamada. *Soc. Mech. Engrs.—Jl.*, (Tokyo), vol. 31, no. 136, Aug. 1928, pp. 420-446, 59 figs.

Author using same method as that of Koerber and Storp with some improvements, obtained stress-strain curve and investigated problems in notched-bar impact test; materials tested were carbon steels containing 0.1, 0.3 and 0.5 per cent of carbon and nickel-chromium steels; test-piece used was of Izod type. (In English.)

INGOT IRON

Pure Iron in Armco Ingots (Le fer pur en lingot Armco), E. Dupuy. *Revue de Métallurgie (Paris)*, vol. 25, no. 11, Nov. 1928, pp. 637-647, 21 figs.

Description of Armco iron, its manufacture, uses, characteristics, resistance to corrosion; micrographic appearance.

IRON

CORROSION. Corrosion Phenomena (Ueber Korrosionserscheinungen), A. Thiel and H. Luckman. *Korrosion und Metallschutz (Berlin)*, vol. 4, no. 7, July 1928, pp. 169-177, 5 figs.

Fourteenth report on University of Marburg studies; effect of pure and weakly alkaline waters on iron at temperatures up to 100 deg. cent.

EXPANSION. Expansion of Iron (La dilation du fer), W. Schreck. *Fonderie Moderne (Paris)*, vol. 22, Nov. 10, 1928, pp. 434-437, 9 figs.

Temperatures and relative expansion of iron are discussed; prolonged heating and its effect; causes of expansion under various conditions.

RUST REMOVAL. Use of Organic Sulphonic Acids for Chemical Removal of Rust (Die Bedeutung der organischen Sulfosäuren fuer die chemische Entrostung), O. Merz. *Archiv fuer Waermewirtschaft (Berlin)*, vol. 9, no. 12, Dec. 1928, pp. 394-395, 1 fig.

Results of tests show that formaldehyde condensation product of naphthalene-sulphonic acid is superior to chemical media heretofore used, as it dissolves rust rapidly, does not attack iron, and eliminates after-treatment with alkalis.

IRON ALLOYS

MANGANESE. Iron Manganese Alloys, V. N. Krivobok. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 634, Dec. 13, 1928, p. 428.

Report of Metallurgical Advisory Board to Carnegie Inst. of Technology and U. S. Bureau of Mines. Preparation and constitution of alloys and determination of specific properties; microscopic studies; carburizing of manganese alloys.

THERMAL EXPANSION. Thermal Expansion of Iron Alloys (Ueber die thermische Ausdehnung von Eisenlegierungen), A. Schulze. *Zeit. fuer Technische Physik (Leipzig)*, no. 9, Sept. 1928, pp. 338-343, 8 figs.

Report from Germany's State Institute of Engineering Physics; data on thermal expansion of iron-silicon, iron-aluminum, and iron-manganese alloys up to 500 deg. cent.

IRON CASTINGS

BLAST FURNACE PRODUCTION. Blast Furnace Metal for Castings, D. Baker. *Iron Age*, vol. 122, no. 24, Dec. 13, 1928, pp. 1501-1502.

Question of whether blast furnace can compete with pipe foundry is discussed; analysis of conditions and costs involved; two 10-hr. shifts a day in foundry recommended; foundry-equipment savings; unit costs tied up with quantity; use of direct blast-furnace metal for production of castings never tried commercially; advantage from mixing iron; qualities required by foundry; fluid iron can be made.

WASTERS. Waster Castings: their Lesson and their Prevention, A. E. McR. Smith. *Foundry Trade Jl. (Lond.)*, vol. 39, no. 634, Dec. 13, 1928, pp. 429-430.

Consideration of causes of wasters in different classes, since each has its own particular types of defects; chief faults in builders' castings mostly consist of molding faults; finish is important in domestic castings; general machinery castings should be capable of being machined all over, without any sign of dirt, blowholes and other defects; for pressure castings, correct composition of metal is requisite; scheme of examination of waster castings.

IRON FOUNDRY PRACTICE

Melting Plant and Appliances in Modern Iron Foundries, J. McLachlan and C. A. Otto. *Iron and Steel Industry (Lond.)*, vol. 2, no. 3, Dec. 1928, pp. 91-94, 5 figs.

Design of charging platforms and hoists, considerations which have profound influence on economy, is discussed; protected staging for melting unit; mixtures and methods of charging; cupola plant in German foundry; relative merits of hand and automatic charging. (Continuation of serial.)

Consider Iron Melting Practice. *Foundry*, vol. 56, no. 24, Dec. 15, 1928, p. 1019.

Review of meeting of National Founders'

Association in New York with abstracts of papers; Automatic Blast Gate Control for Cupolas, H. V. Crawford; Melting Practice, H. M. Lane; Foundry Costs, J. L. Carter; Foremanship Training, K. A. Hartley.

IRON AND STEEL

UTILIZATION — ELECTRIC INDUSTRY. Iron, Steel and Ferrous Alloys in the Electrical Industry, J. G. Pearce. *Electn. (Lond.)*, vol. 101, no. 2635, Nov. 30, 1928, pp. 604-606, 1 fig.

Wide use of cast iron; competition of fabricated steel; electric and magnetic considerations; electric furnaces and special steels; new heat-resisting non-scaling steels; tungsten steel for permanent magnets.

IRON AND STEEL INDUSTRY

RAW MATERIALS — GERMANY. Raw-Material Supply of the German Iron and Steel Industry (Die Rohstoffversorgung der deutschen Eisen schaffenden Industrie), H. Niebuhr. *Stahl und Eisen (Duesseldorf)*, vol. 48, no. 48, Nov. 29, 1928, pp. 1672-1674.

Statistical data on supply of ore and scrap, based on committee report.

IRON AND STEEL PLANTS

ELECTRIC FURNACES. The Electric Furnace in the Different Plants of the Société des Acieries Firminy (Le four électrique dans les diverses usines de la Société des Acieries de Firminy), R. Sevin. *Jl. du Four Electrique (Paris)*, vol. 37, no. 11, Nov. 1928, pp. 335-337.

Description of electric furnaces at various plants of steel company; generating units, steam power, electric apparatus, and rolling mills are also described.

FUEL ECONOMY. Fuel Control in Forge and Rolling-Mill Practice, H. C. Armstrong. *Iron and Coal Trades Rev. (Lond.)*, vol. 117, no. 3170, Nov. 30, 1928, pp. 791-792, 3 figs.

Recording fuel consumption; maintaining furnace at definite temperature; thermal efficiency; increase in fuel consumption with intermittent working; tests to ascertain correct consumption; control of steam consumption; value of constant pressure. Paper read before Inst. of Fuel.

FUEL ECONOMY. Controlling Fuel in Steel Plants. *Iron Age*, vol. 122, no. 25, Dec. 20, 1928, p. 1585.

Review of meeting of (British) Institute of Fuels in London with abstracts of papers; fuel oil to be used economically must be correctly atomized, M. J. Conway; Fuel Control in Open-Hearth Practice, J. L. Bentley; Fuel Control in Forge and Rolling Mill Practice, H. C. Armstrong; Fuel Control in Hot Blast Stoves, J. B. Fortune.

FURNACE INSULATION. Value of Insulation in the Steel Plant, L. B. McMillan and J. D. Van Valkenburgh. *Blast Furnace and Steel Plant*, vol. 16, no. 12, Dec. 1928, pp. 1560-1566, 11 figs.

Utility of insulation in blast furnace and steel plant is discussed; heat wasted by radiation; factors governing insulation thickness; direct savings in heat loss; economical thickness of insulation; insulation on blast furnace and accessory of insulation; insulation on blast furnace and accessory equipment, open-hearth and soaking pit, rolling-mill furnaces and equipment, annealing and

normalizing furnaces, and in producer-gas mains. See also Heat Treating and Forging, vol. 14, no. 12, Dec. 1928, pp. 1453-1458, 11 figs.

MALLEABLE IRON CASTINGS

Malleable Cast Iron, C. H. Plant. *Iron and Steel Industry (Lond.)*, vol. 2, no. 3, Dec. 1928, pp. 89-90 and 94, 1 fig.

Practical details of annealing of white-heart castings, most important processes in manufacture of malleable castings; advantages of gas-fired furnaces; employment of regeneration; great advantage derived by installing gas-producer unit in connection with furnace; modern types of annealing furnaces; systems of charging furnaces. (Continuation of serial.)

MANGANESE STEEL

Pure Manganese Makes Interesting Alloys. *Iron Age*, vol. 122, no. 24, Dec. 13, 1928, pp. 1499-1500, 2 figs.

In research into alloys of iron and manganese under way at Bureau of Metallurgical Research, Carnegie Institute of Technology, manganese metal and iron-manganese alloys of unusual purity were prepared; British and Americans prepared 99.99 per cent metal; carbon-free alloys much tougher than corresponding low carbon manganese steels; vacuum distillation method described by M. L. V. Gayler before (Brit.) Iron and Steel Inst. in 1927.

METALS

ENDURANCE TESTING. A Rapid Method of Determining Endurance Limit by Means of Measuring Electrical Resistance, S. Ikeda. *Soc. Mech. Engrs.—Jl. (Tokyo)*, vol. 31, no. 136, Aug. 1928, pp. 447-466, 31 figs.

Electrical resistance in steel specimens subjected to repeated bending stress was measured for different increasing stresses; relation between newly observed endurance limit and Shore's hardness number was shown. (In English.)

FATIGUE. The Endurance Properties of Metals. *Engineering (Lond.)*, vol. 126, no. 3279, Nov. 16, 1928, pp. 636-637.

Review of several papers dealing with various forms of fatigue to which metals are exposed presented at meeting of Am. Society Testing Materials, June 25 to 29; static and fatigue properties of cast iron; corrosion and corrosion fatigue; creep tests of carbon steels; wear tests.

FATIGUE. The Nature of Fatigue, Laute and Sachs. *Metallurgist (Supp. to Engineer, Lond.)*, Nov. 30, 1928, pp. 173-174.

Experiments with single crystals show that fatigue only sets in after appreciable deformation and hardening by slip; high degree of hardening, however, retards deformation of material, so that fatigue may be explained on basis of reduction of resistance by reversal of shear stresses; on other hand, there seems to be evidence that fatigue may be due to breakdown in structure of material, quite independent of degree of hardening. Abstract translated from V. D. I. Zeit., Aug. 25, 1928.

HARDENING. Cold and Hot Working of Metals, W. Rosenhain. *Metallurgist (Supp. to Engineer, Lond.)*, Nov. 30, 1928, pp. 168-169.

Newer facts which have been revealed by

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modern systematic study of behavior of soft metals at room temperatures and of hard metals at high temperatures, serve as strong confirmation of proximate correctness of conception that ordinary "work hardening" is due to indirect effects of irregular layers produced by slip. (Concluded.)

MACHINABILITY. Machinability, E. G. Herbert. *Machp. (Lond.)*, vol. 33, no. 845, Dec. 20, 1928, p. 374.

No quantitative relationship exists between machinability of metals and physical properties they possess before subjected to work-hardening process of machining; law of machinability; factors influencing hardness of chips. Abstract of Report on Machinability presented before (British) Instn. Mech. Engrs.

SINGLE CRYSTALS. Single-Crystal Metals, Their Preparation and Properties (Les métaux monocristallins, leur préparation et leurs propriétés), M. Privat. *Revue Générale des Sciences (Paris)*, vol. 39, no. 12, June 30, 1928, pp. 363-369, 10 figs.

Description of methods of obtaining large metallic crystals and properties of metals in monocrystalline state.

STRAIN ANALYSIS. Notes on the General Theories of Strain and Elasticity, C. Suriani. *Soc. Mech. Engrs.—Jl. (Tokyo)*, vol. 31, no. 136, Aug. 1928, pp. 635-671, 7 figs.

Strain problems in general deformation are treated with methods and observations different from usual theory of general strain and elasticity; general strain is investigated; obscurity in usual definitions for strains is made clear, and it is shown that usual measure of shear strain is not strictly proper; strain problems treated and expressed by use of vector quantities; besides analytical treatment; strain problems are illustrated graphically by means of strain ellipsoid and by plane diagram. (In English.)

TEMPERATURE EFFECT. Electrical Behavior of Metals in the Neighborhood of the Temperature of Liquid Helium, W. Meissner. *Information on Refrigeration (Institut International du Froid)—Monthly Bul.*, vol. 9, no. 3, May-June 1928, pp. 384-388.

Boiling point of helium under normal pressure, at 760 mm. of mercury is 4.2 deg. abs.; measurements of electric resistance and thermal power of metals; it has not yet been possible to explain with certainty theory of superconductivity; measurements confirmed that ideally pure metals would have extremely low resistance in liquid helium, although this resistance is not incommensurably small. Translated from *Zeit. fuer die gesamte Kaelte-Industrie*, Nov. 1927.

TESTING. Recent Progress in Metal Testing at the 11th International Aeronautic Exposition June-July 1928 (Les récents progrès des essais métallurgiques la 11 Exposition Internationale de l'Aéronautique 29 Juin-15 Juillet 1928), J. Galibourg. *Revue de Métallurgie (Paris)*, vol. 25, no. 11, Nov. 1928, pp. 593-613, 39 figs.

Description of methods and machine used in metal testing as exhibited at Paris aeronautic exhibition; mechanical, micrographic radiographic, magnetic, chemical and other tests.

TESTING—STRAIN FIGURES. The Properties of Strain Figure and Its Applications,

I. Takaba. *Soc. Mech. Engrs.—Jl. (Tokyo)*, vol. 31, no. 137, Sept. 1928, pp. 350-365, 28 figs.

Features of strain figure are referred to stress distribution from results of optical determination of stress; close connection between strain figure and yielding point. (In Japanese.)

METAL WORKING

Welding Facts and Figures, D. Richardson and E. W. Birch. *Welding Jl.*, vol. 25, no. 302, Nov. 1928, pp. 326-329, 1 fig.

General machining operations broadly classified; characteristics of commercial cast irons and steels; grading of tool steel; influence of carbon in cast iron.

METALLOGRAPHY

Metallography Simplified for Practical Use in Shop, E. Preuss, G. Berndt and M. V. Schwarz. *Iron Trade Rev.*, vol. 83, no. 24, Dec. 13, 1928, pp. 1496-1498, 10 figs.

Structural changes which take place in steel when it is forged are explained; numerous photomicrographs illustrate type of structures encountered in steels of various carbon contents; steel must be annealed first if carbon content is to be estimated from micrograph; in overheated steel and steel cooled too fast after casting, carbon content easily is estimated too high; after proper annealing structure is homogenized and estimate carried out is reliable. (Continuation of serial.)

METALLURGICAL PLANTS

CHEMICAL ANALYSIS. Methods of Chemical Analysis in Iron and Steel Works (Les méthodes d'analyses courantes dans les usines métallurgiques), L. Persoz. *Revue de Chimie Industrielle (Paris)*, vol. 37, no. 442, Oct. 1928, pp. 327-329.

Determination of molybdenum, titanium, copper, aluminum, uranium, and zirconium.

MONEL METAL

Monel Metal (Ueber das Monel-Metall), A. Schulze. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 11, Nov. 1928, pp. 403-406, 4 figs.

Part 1: Notes on electric and thermal properties and magnetostriction. Part 2: Magnetization curves of Monel metal.

NICKEL

ANALYSIS. Standard Analysis of Nickel. *Chem. England and Min. Rev. (Melbourne)*, vol. 21, no. 241, Oct. 4, 1928, pp. 33-35.

Details of laboratory methods, as furnished by Munitions Supply Board, Commonwealth Dept. of Defense.

HARDNESS. Relation of Impact Hardness of Nickel to Temperature (Ueber die Abhängigkeit der Fallhaerte des Nickels von der Temperatur), F. Sauerwald. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 11, Nov. 1928, pp. 408-409, 1 fig.

Impact hardness of nickel begins to decrease to greater extent at about 300 deg. cent. and shows at 450 deg. maximum value; first fact, as well as tensile tests, lead to assumption that magnetic point of transformation has influence on mechanical properties; second fact leads to assumption of presence of blue-brittleness phenomena.

RAILS

STEEL—HEAT TREATMENT. Heat Treatment of Rails, Marcotte. *Metallurgist (Supp. to Engineer, Lond.)*, Nov. 30, 1928, pp. 167-168.

Notes on heat treatment of rails as means of improving their behavior in service, with particular reference to undulatory wear on street railways.

STEEL—PROPERTIES. Mechanical Properties of British Rail-Steels, W. E. Dalby. *Instn. Civil Engrs.—Proc. (Lond.)*, vol. 227, part 1, no. 4690, 15 pp., 31 figs. on supp. plates.

Continuation of work described in author's paper on "Mechanical Properties of Steel," with special reference to mechanical properties of steels used for rails on British railways; no-load-to-fracture diagrams in comparison; push-pull diagrams; torque twist diagrams; elastic diagrams; microphotographs of inner structure; slipping stress; stress in rail.

TRANSVERSE FISSURES—DETECTION. Transverse Fissure is No Longer a Hidden Menace. *Ry. Eng. and Maintenance*, vol. 24, no. 12, Dec. 1928, pp. 521-526, 11 figs.

Newly developed device for finding concealed defects in rails; Sperry transverse-fissure detector developed for, and with co-operation of Am. Ry. Assn. and Am. Ry. Eng. Assn.; general description of new equipment; principal units of detector equipment; electric equipment and circuits; how equipment detects defects; makes paper record of all defects; first service run of equipment; many cooperated in developing detector car; second car now engaged in commercial work; changes in newer car.

WEAR. Effect of Condition of Track on Wear of Rails (Einfluss der Beschaffenheit des Gleises auf die Abnutzung der Schienen). L. Lubimoff. *Organ fuer die Fortschritte des Eisenbahnwesens (Munich)*, vol. 83, no. 20, Oct. 15, 1928, pp. 438-442, 3 figs.

Brief report on series of observations on three main railroad lines in Russia; effect of condition of ballast, ties, slope of rails, composition of rail steel, etc.

ROLLING MILLS

ELECTRIC DRIVE. The Electric Driving of Rolling Mills. *Mech. World (Manchester)*, vol. 84, no. 2186, Nov. 23, 1928, pp. 492-493, 4 figs.

General description of electric-drive requirements in rolling mills precedes details of new electrically driven plant recently installed by Appleby Iron Co.; direct drive most suitable form for non-reversing mills; special types of starters; speed regulation of driving motors; special types of motors built for reversing rolling mills; switchgear.

ELECTRIC DRIVE. Studies of Power Requirement in Continuous Rolling Mills with Electric Drive (Kraftbedarfsstudien in durchlaufenden elektrisch angetrieben Walzentrassen). A. Werth. *Archiv. fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 5, Nov. 1928, pp. 301-308, including discussion, 16 figs.

Notes on differences in power requirement of mills of similar cross-sections; explanation of term, specific productive rolling work (bezogene Lastmehrarbeit), by which is understood that work that roll motor has to perform in excess of work at no-load; results of tests. See abstracts in Stahl u.-Eisen, vol.

48, no. 48, Nov. 29, 1928, pp. 1670-1671, 3 figs.

STEEL

CAST VS. FORGED. Study of Cast and Forged Steel, S. V. Belinsky. *Vestnik Metallopromyshlennosti (Moscow)*, vol. 8, no. 7-8, July-Aug. 1928, pp. 55-64, 3 figs.

Comparative experimental study of cast and forged steel; cast steel greatly improved by heat treatment; forging per se is harmful to steel; superiority of forged steel due to heat treatment accompanying forging. (In Russian.)

HEAT TREATMENT. The Effects of Heating Temperature and Time, and Also Aging Upon the Internal Stresses in a Cold Worked Mild Steel, E. Murata. *Soc. Mech. Engrs.—Jl. (Tokyo)*, vol. 31, no. 136, Aug. 1928, pp. 366-390, 12 figs.

Writer has measured change of initial stresses in cold mild steel shaft under various temperatures and durations of heating, and also aging, by Heyn's method using Zeiss' optimeter. (In Japanese.)

HEAT TREATMENT. Heat Treatment of Steel, H. M. Boylston. *Black and White (Metal Sec.)*, vol. 1, no. 5, Oct. 1928, pp. 11-14.

Heat treatment of structural carbon steel; importance of heating steel above Ac-3 and Ac-3.2 temperatures; full annealing of structural steel; patenting; quenching and drawing operations; precautions to be observed in quenching operations; shop annealing.

HEAT TREATMENT—CRITICAL POINTS. Critical Points of Pure Iron and Pure Carbon Steels, T. S. Kogakusi. *Soc. Mech. Engrs.—Jl. (Tokyo)*, vol. 31, no. 137, Sept. 1928, pp. 914-917.

Critical points of pure iron and pure carbon steels studied; degree of superheating and supercooling of critical points corresponding to different rates, determined; critical points in equilibrium condition were deduced and equilibrium diagram of iron-cementite system constructed. (In Japanese.)

HEAT TREATMENT—QUENCHING. Quenching, H. C. Knerr. *Black and White (Metal Sec.)*, vol. 1, no. 5, Oct. 1928, pp. 3-6.

Fallacy of absorption theory; quenching mediums; importance of correct temperature; rate of cooling during quenching; quenching entails greatest number of variables of all heat-treating operations.

MAGNETIC TESTING. What Magnetic Testing Reveals, A. V. de Forest. *Iron Age*, vol. 122, no. 25, Dec. 20, 1928, pp. 1573-1574.

More knowledge of uniformity and continuity of steel gained; facts which other methods of test bring out; limitations of all tests. Paper based on comments when presenting motion pictures of magnetic tests before Am. Iron and Steel Inst.

PROPERTIES. Grain Size Controls Toughness, T. W. Hardy. *Iron Age*, vol. 122, no. 25, Dec. 20, 1928, pp. 1557-1562, 9 figs.

McQuaid-Ehn test necessary to distinguish between heats of steel with same chemical analysis yet responding differently in mass production; close chemical control in basic electric process; hardening power of fine-grained versus coarse-grained steels; superior machining quality of coarse-grained steel; mechanical properties of fine-grained steels; most important property is wide temperature range in heat treatment.

1929

TENTATIVE DEFINITIONS OF TERMS RELATING TO HEAT TREATMENT OPERATIONS

DURING the past year the Joint Committee on Terms Relating to Heat Treating Operations has added additional definitions to the report previously prepared by the Joint Committee and which is published in the A. S. S. T. HANDBOOK, page 71. These additional definitions are given below.

It was also recommended by the Joint Committee that all of the definitions remain in tentative form for at least another year. The Joint Committee consists of 3 representatives from the American Society for Steel Treating; 3 representatives from the American Society for Testing Materials and 3 representatives from the Society of Automotive Engineers. The A. S. S. T. representatives are: J. Fletcher Harper; W. J. Merten and Bradley Stoughton.

Insert after the definition of the term "annealing" definitions of the terms "full annealing" and "process annealing" to read as follows:

Full Annealing.—Heating iron-base alloys above the critical temperature range, holding above that range for a proper period of time followed by slow cooling through the range.

NOTE:—The annealing temperature is generally about 100 degrees Fahr. (55 degrees Cent.) above the upper limit of the critical temperature range, and the time of holding is usually not less than one hour for each inch of section of the heaviest objects being treated. The objects being treated are ordinarily allowed to cool slowly in the furnace. They may, however, be removed from the furnace, and cooled in some medium which will prolong the time of cooling as compared to unrestricted cooling in the air.

Process Annealing.—Heating iron-base alloys to a temperature below or close to the lower limit of the critical range followed by cooling as desired.

NOTE:—This heat treatment is commonly applied in the sheet and wire industries and the temperatures generally used are from 1020 to 1200 degrees Fahr. (550 to 650 degrees Cent.).

Insert after the definition of the term "normalizing" a definition of the term "patenting" to read as follows:

Patenting.—Heating iron-base alloys above the critical temperature range followed by cooling to below that range in molten lead maintained at a temperature of about 700 degrees Fahr. (365 degrees Cent.).

NOTE:—This treatment is usually applied in the wire industry either as a finishing treatment or especially in the case of eutectoid steel as a treatment previous to further wire drawing. Its purpose is to produce a sorbitic structure.

News of the Society

THE WESTERN METAL CONGRESS AND WESTERN STATES METAL AND MACHINERY EXPOSITION

Los Angeles, January 14-18, 1929

MOST gratifying were the results of the first Western Metal Congress and Western States Metal and Machinery Exposition held in the Shrine Auditorium in the city of Los Angeles, January 14-18, 1929.

The Exposition under the direction of the American Society for Steel Treating was the first of its kind ever to be held in the West and from the splendid response both by the Exhibitors and the interested public, this Exposition proved to be more successful and interesting than even the most optimistic had hoped.

It surely must be a source of great satisfaction to the members of the Los Angeles Chapter and especially to those members who served so diligently and willingly on the various committees on arrangements, to know that their efforts were so instrumental in bringing about the success of this convention.

The Congress was sponsored by twelve technical societies and associations and proved to be of great interest to the technically inclined—there being an average attendance of between 200 and 300 at each of the ten technical sessions held throughout the week. The program of the Congress was widely diversified, having an appeal not only to those interested in metals, but those interested in the oil industry as well. Much interesting and valuable discussion followed the presentation of papers. The morning sessions were held in the music room of the Hotel Biltmore, and the afternoon sessions were held in the meeting room of the Shrine Auditorium. In the preparation of the program for the Western Metal Congress we are indebted for the splendid support and co-operation received from the western branches of the following societies and associations:

American Foundrymen's Association
American Institute of Mining and Metallurgical Engineers
American Society of Mechanical Engineers
American Welding Society
California Division American Petroleum Institute
Chamber of Mines and Oils
Institute of Metals
Metal Trades and Manufacturers Association
National Purchasing Agents Association
Pacific Coast Electrical Association
Pacific Coast Gas Association
Society of Automotive Engineers

More than 175 manufacturers and distributors of machinery, metals, heat treating equipment, small tools, electric units and oil well tools and

equipment exhibited products ranging from the raw material to the finished units. This exhibition occupied somewhat in excess of 30,000 square feet of exhibition space—filling the main floor as well as the lower floor of the spacious Shrine Auditorium. The exhibits were novel and arranged in an interesting manner as can be seen from the accompanying pictures of some of the exhibits at the show. The Exposition was opened at 12 noon each day, and remained open until 10 o'clock in the evening, with the exception of Thursday, when it closed at 6:00 p. m., in order to leave the evening open for the informal dinner-dance at the Hotel Biltmore.

Throughout the week 9,000 members and guests registered as in attendance at the Exposition, while there was a total attendance at the Exposition of more than 50,000 people for the 5 days.

In order that those members of the Society who were unable to be in attendance at the first Western Metal Conference may have a glimpse of what happened during the week, we are publishing in some detail an account of the events. The following is arranged in chronological order. In accordance with the method used in semi-annual meetings and the annual convention in the East, an accurately arranged time schedule was provided for the presentation of each paper and the author and discussors were held to the time allowance for the presentation of each paper.

MONDAY, JANUARY 14

The first technical session was called to order at 10:00 a. m. by Wade W. Hampton, chairman of the Los Angeles Chapter of the American Society for Steel Treating. Mr. Hampton extended a cordial greeting of welcome to the 250 members and guests who assembled to hear the four papers which were presented at this session. In response to this greeting, Dr. Zay Jeffries, president of the Society, expressed his sincere appreciation to the members of the Los Angeles Chapter of the Society and to those co-operating societies and associations for their excellent support in arranging for the various activities during the week of the Western Metal Congress and Western States Metal and Machinery Exposition.

Following these preliminaries, Professor W. H. Clapp, head of the Department of Metallurgy and Machine Design, California Institute of Technology, acted as chairman of the session. Four papers were presented in the following order:

- 10:10-10:40—*The Importance of Shops in University Training*—Arthur B. Domonoske, executive head, Mechanical Engineering Department, Stanford University, California.
- 10:40-11:10—*Some Observations on the Application of Mechanical Testing to Design*—Prof. W. H. Clapp, Dept. of Metallurgy and Machine Design, California Institute of Technology, Pasadena, Calif.
- 11:10-11:40—*Heat Treatment of Dies, Tools and Gears*—Jordan Korp, engineer, Leeds and Northrup Co., Philadelphia.
- 11:40-12:10—*Design in Relation to Heat Treatment*—Ray T. Bayless, Editor of TRANSACTIONS, American Society for Steel Treating, Cleveland.



VIEWS OF THE EXPOSITION

The second technical session was held in the meeting room of the Shrine Auditorium and convened at 2:00 p. m., with 200 persons in attendance. This meeting was sponsored by the Metal Trades and Manufacturers Association and was under the chairmanship of Carroll A. Stilson, secretary of the association. Four papers were scheduled for presentation, all of which were presented by their respective authors. The papers were as follows:

- 2:00- 2:30—*Foundry Sand Control*—A. A. Grubb, Mansfield, Ohio, member of A. F. A. Sand Testing Committee.
2:30- 3:00—*Nickel-Chrome Alloy Iron*—W. R. Shimer, metallurgical engineer, Bethlehem Steel Corp., Bethlehem, Pa.
3:00- 3:30—*Heat Treatment of Carbon and Alloy Steel Castings*—J. E. Donnellan, secretary, Recommended Practice Committee, American Society for Steel Treating, Cleveland.
3:30- 4:00—*Furnaces*—R. E. Talley, president, George J. Hagan Co., Pittsburgh.

TUESDAY, JANUARY 15

The third technical session of the Western Metal Congress was held in the music room of the Hotel Biltmore and was called to order by Chairman L. W. Voorhees, mechanical engineer, Union Oil Co. of California. Four papers were scheduled for presentation, all of which were presented by their respective authors and in the following order:

- 10:00-10:30—*Metals and Alloys for Industrial Applications Requiring Extreme Stability*—Jerome Strauss, chief research metallurgist, Vanadium Corp. of America, New York.
10:30-11:00—*Valves and Fittings, Materials, Design and Application for High Pressure—High Temperature Oil Refining*—V. T. Malcolm, metallurgical engineer, Chapman Valve Co., Indian Orchard, Massachusetts.
11:00-11:30—*Tendency Toward Higher Steam Pressures in Both Marine and Stationary Services, the Materials Available for the Construction of Boilers for these Higher Pressures, and Some of the Factors Involved in their Design*—Robert L. Daugherty, professor mechanical engineering, California Institute of Technology, Pasadena, Calif.
11:30-12:00—*Heat Insulation and Refractories in Connection with Furnace Design*—Guy A. Barker, manager of the industrial department, Pacific Division, Johns-Manville, Inc., San Francisco.

About 250 persons were present at this meeting.

The fourth technical session, sponsored by the American Society of Mechanical Engineers and under the chairmanship of H. H. Anderson of the Shell Oil Co., convened at 2:00 p. m. in the Shrine Auditorium meeting room. This meeting pertained largely to oil well tools and created much interest among the oil well fraternity. The papers presented are as follows:

- 2:00- 2:30—*The Manufacture of Rotary Tool Joints*—W. H. Fisher, chief



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metallurgist, and A. H. Mártois, research department, Emsco Derrick and Equipment Co., Los Angeles.

2:30- 3:00—*Cast Steel Slush Pump Cylinders*—Lester Keim, general manager, Oil Well Supply Co. of California, Los Angeles.

3:00- 3:30—*The Development and Manufacture of Rotary Driving Grief Stems*—Glenn C. Merkley, engineering department, National Supply Co. of California, Torrance, California.

3:30- 4:00—*Sucker Rods*—W. H. Laury, research engineer, Axelson Machine Co., Los Angeles.

WEDNESDAY, JANUARY 16

The fifth technical session of the Congress convened at 10:00 a. m. in the music room of the Hotel Biltmore, and was sponsored by the California Division of Development and Production Engineering of the American Petroleum Institute, and was under the chairmanship of A. C. Rubel of the Union Oil Co. Two papers were presented at this session as follows:

10:00-11:00—*Sucker Rod Strains and Stresses*—F. W. Lake, superintendent of operations, Orange County Division, Union Oil Co., Los Angeles.

11:00-12:00—*Oil String Failures*—C. J. Coberly, president, Kobe, Inc., Los Angeles.

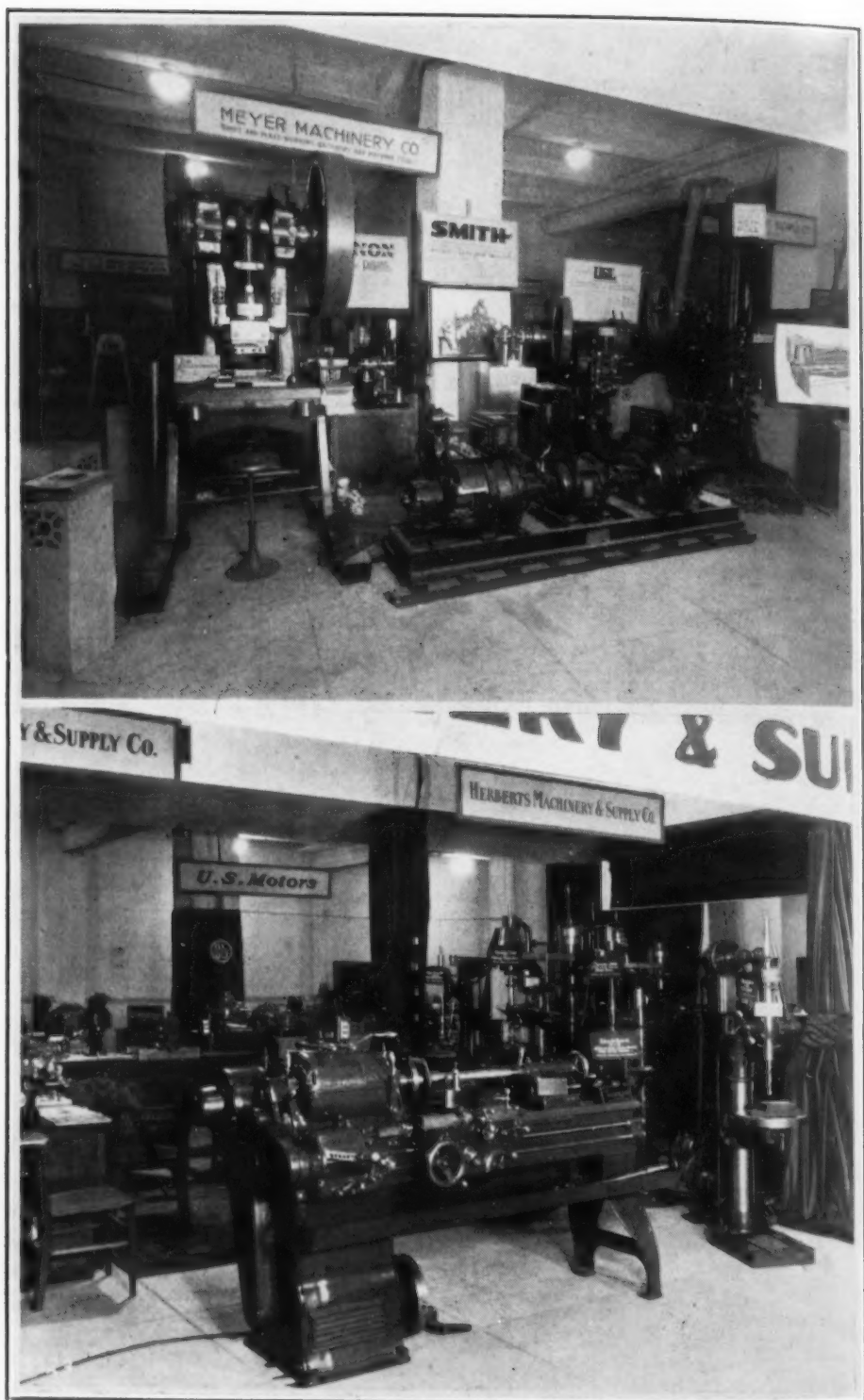
The first paper discussed in considerable detail the problem of sucker rod failures, and made a plea for the need of better tools and better methods of heat treating in order to lessen the failure of deep pumping operations. The second paper was a lengthy dissertation upon the failure of the "oil string" or the oil pipe line which goes down into the well. The author discussed the various types of failures which occur in oil strings and pointed out that some failures are the cause of great trouble and much loss in production of oil. This paper was the result of the compilation of a large amount of field data as well as research work. About 200 members and guests attended this session.

The sixth technical session, sponsored by the American Institute of Mining and Metallurgical Engineers, under the chairmanship of R. R. Boyd of the Richfield Oil Co., was called to order by the chairman at 2:00 p. m. in the meeting room of the Shrine Auditorium. Four papers were presented at this session as follows:

2:00- 2:30—*On the Double Diagram of the Iron-Carbon System*—Dr. Kotaro Honda, Research Institute for Iron and Steel, Imperial University, Sendai, Japan.

2:30- 3:00—*Proposed Metallurgical Control for Small Heat Treating Plants*—Dr. Welton J. Crook, professor of metallurgy, Stanford University, California.

3:00- 3:30—*Standard Complete Factory-Built 25-50 Ton Flotation Mills*—J. P. Shimmin, chief engineer, Southwestern Engineering Corp., Los Angeles.



VIEWS OF THE EXPOSITION

3:30-4:00—*Heat Treatment of Gears*—W. H. Phillips, vice-president, Molybdenum Corp. of America, Pittsburgh.

At the request of Chairman Boyd, Dr. Jeffries introduced Dr. Kotaro Honda of the Imperial University at Sendai, Japan, and honorary member of the A. S. S. T., who journeyed to America as the special representative of the Japanese government to the Western Metal Congress. Dr. Honda then presented his paper. The remaining three papers were then presented in their order and by their respective authors. 150 members and guests attended this session.

THURSDAY, JANUARY 17

The seventh technical session, sponsored by the Pacific Gas Association and under the chairmanship of C. M. Grow of the Southern California Gas Co., was called to order at 10:00 a. m. Six papers were presented at this session and in the following order:

- 10:00-10:25—*Advantages and Disadvantages of Oil, Gas and Electric Fired Furnaces*—C. B. Phillips, vice-president, Surface Combustion Co., Toledo, Ohio.
- 10:25-10:50—*Heat Treating Furnace Design*—J. H. Gumz, industrial engineer, Pacific Gas and Electric Corp., San Francisco.
- 10:50-11:15—*Existing Heat Treating Installations*—E. M. DeRemer, industrial engineer, Southern California Gas Co., Los Angeles.
- 11:15-11:30—*What the Gas Companies Are Doing for Industrial Heating*—C. M. Grow, new business manager, Southern California Gas Co., Los Angeles.
- 11:30-11:45—*Gas as Applied to Carburizing*—written by P. C. Osterman and E. C. Cook, American Gas Furnace Co., Elizabeth, N. J., read by E. M. DeRemer.
- 11:45-12:05—*The Use of City Gas in the Carburizing of Iron and Steel*—Robert G. Guthrie, metallurgist, Peoples Gas Light and Coke Co., Chicago. Paper read by R. A. Hornby, Southern California Gas Co.

Each author restricted himself to the time limit provided. The attendance at this session was about 200.

The eighth technical session was sponsored by the Pacific Coast Electrical Association, and was under the chairmanship of R. C. McFadden of the Southern California Edison Co. It convened at 2:00 p. m., and three papers were presented on this program. They were as follows:

- 2:00-2:30—*Address*—Paul Downing, vice-president, Pacific Gas and Electric Corp., and president of the Pacific Coast Electrical Association, San Francisco.
- 2:30-3:30—*The Use of Electricity in the Heat Treatment and Welding of Metals*—C. L. Ipsen, A. N. Otis and W. L. Warner. Presented by N. R. Stansel. All men are associated with the General Electric Co., Schenectady, N. Y.
- 3:30-4:00—*Electric Heat and Its Application to Heat Treating*—P. C.



VIEWS OF THE EXPOSITION

Kelly, Westinghouse Electric and Manufacturing Co., Mansfield, Ohio.

The number of persons attending this session was 250.

The exposition closed at 6:00 p. m. on Thursday evening in order to leave the evening open for the informal dinner-dance which was held in the banquet room of the Hotel Biltmore at 8:00 p. m.

This evening proved to be a very interesting occasion, consisting of a dinner-dance interspersed with entertaining and amusing vaudeville numbers. More than 500 attended this event which lasted until 1:00 a. m.

FRIDAY, JANUARY 18

The ninth technical session of the Western Metal Congress was sponsored by the Society of Automotive Engineers and was under the chairmanship of Ethelbert Favary, consulting engineer, Moreland Motor Truck Co. Five papers were presented before this session in the following order:

- 10:00-10:25—*Manufacture and Heat Treatment of Automobile Leaf Springs*—J. B. Rauert, general manager, U. S. Spring Co., Los Angeles.
10:25-10:50—*Production of Nickel Steel Castings by Electric Furnace Method*—E. Favary, consulting engineer, Moreland Motor Truck Co., Burbank, Calif.
10:50-11:15—*Aluminum as Applied to the Automotive and Airplane Industry*—Dr. Zay Jeffries, chief research engineer, Aluminum Co. of America, Cleveland.
11:15-11:40—*The Use of Metal in Aircraft Construction*—J. H. Kindelberger, chief engineer, Douglas Aircraft Co., Santa Monica, California.
11:40-12:05—*Metallurgical and Heat Treating Problems in Motor Car Manufacture (illustrated with moving pictures)*—J. M. Watson, chief metallurgist, Hupp Motor Car Co., Detroit.

The attendance at this meeting exceeded 250.

The tenth and final session of the Congress, sponsored by the American Welding Society and under the chairmanship of A. E. Deburn, chief engineer, Pacific Pipe and Supply Co., was called to order by the chairman at 2:00 p. m. Three papers were scheduled for presentation at this session. They were presented in the following order:

- 2:00-2:45—*The Welding of Steel Buildings and Bridges*—Dr. Frank P. McKibbin, consulting engineer for the General Electric Co., Schenectady.
2:45-3:15—*Heat Treatment with Oxyacetylene Flame*—J. J. Bruton, service engineer, Ox-weld Acetylene Co., New York.
3:15-4:00—*Building Machinery with Arc Welded Steel Replacing Castings*—David Hall, district engineer, Westinghouse Electric and Mfg. Co., Los Angeles.

This meeting was especially well attended, there being about 350 present. All of the papers were presented by their respective authors and much



VIEWS OF THE EXPOSITION

interesting discussion was brought out, especially so in the case of the first paper, presented by Dr. F. P. McKibben.

Plant Inspection

Interesting plant inspection trips were provided by the committee on plant inspection under the chairmanship of W. W. Farrar. These inspection trips were scheduled for Tuesday, Wednesday, Thursday and Friday mornings. The committee made arrangements for the inspection of the following plants, and the Congress is indebted to these concerns for their willingness to co-operate in this phase of the program.

Oil field inspection, Signal Hill, Shell Company; General Petroleum Corporation; Emsco Forging Company; Western Drop Forge Company; Axelson Machine Company; Union Tool Company, Torrance; Doheny Stone Drill Company, Lomita; The Stooddy Company, Whittier; H. C. Smith Company, Los Nietos; Emsco Derrick and Equipment Company; Western Air Express, Vail Field; Southern California Edison Steam Plant, Long Beach; Union Pacific Railway Shops, Los Angeles; Columbia Steel Mills, Torrance; and Llewellyn Iron Works.

It was gratifying to note that many members and guests took advantage of these plant inspection trips.

Ladies' Entertainment

An interesting program for the entertainment of visiting ladies had been arranged by J. H. Knapp, chairman of the ladies' entertainment committee. The various events which made up this program were as follows:

MONDAY, JANUARY 14

Luncheon at Hotel Biltmore followed by sight-seeing tour to Hollywood, Beverly Hills and the Beaches.

TUESDAY, JANUARY 15

Trip to a Moving Picture Studio.

WEDNESDAY, JANUARY 16

Auto sight-seeing trip to Pasadena and surrounding territory, including visits to the Alligator farm and Ostrich farm.

THURSDAY, JANUARY 17

Dinner-Dance-Entertainment in the Ballroom, Biltmore Hotel.

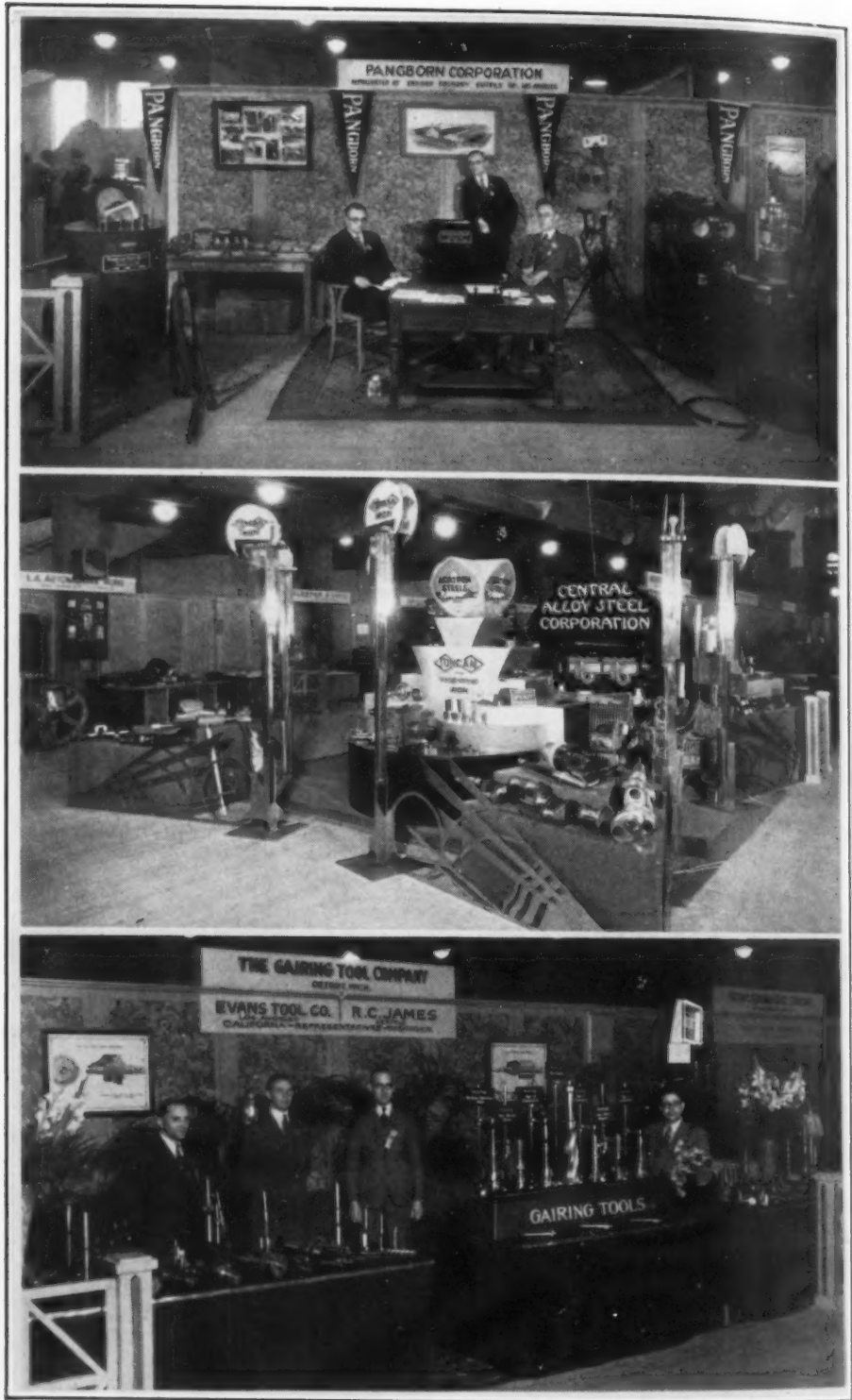
FRIDAY, JANUARY 18

Moving picture theatre party to Grauman's famous Chinese Theatre, Hollywood.

There were about 75 ladies in attendance.

Lectures by J. F. Keller

One of the outstanding features of the Western Metal Congress was the course of lectures on metallurgy and heat treatment delivered by Professor



VIEWS OF THE EXPOSITION

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John F. Keller, presented each afternoon at 4:00 p. m., from Monday through Friday. There was an enrollment of about 120 in this course of lectures and from many favorable comments which were heard, we are sure that Professor Keller's lectures were profitable and interesting to all in attendance.

In view of the fact that the first Western Metal Congress and Western States Metal and Machinery Exposition met with such unanimous approval and success, both among the exhibitors and members in the west, the board of directors of the society has authorized a second Congress and Exposition to be held in California in 1931. Definite plans as to the city in which it is to be held have not been made.

The following is a complete list of those companies and individuals who exhibited their products at the exposition.

ABRASIVE COMPANY
AELIUM COMPANY
AERONAUTICAL WORLD
AHLBERG BEARING CO. OF CALIFORNIA
AIRCRAFT HOLDING CORPORATION
AIR REDUCTION SALES COMPANY
AJAX ELECTROTHERMIC CORP.
ALCORN COMBUSTION COMPANY
AMERICAN BRASS COMPANY
AMERICAN CAR AND FOUNDRY CO.
AMERICAN FOUNDRYMEN'S ASS'N
ARMSTRONG-BLUM MFG. CO.
ARMSTRONG BROTHERS TOOL CO.
ASQUITH AND SON, F. A.
ATKINS AND COMPANY, E. C.
ATLAS STEEL CORPORATION
AXELSON MACHINE COMPANY

BALDWIN CHAIN COMPANY
BAUSCH AND LOMB OPTICAL CO.
BETHLEHEM STEEL COMPANY
BIGNALL AND KEELER MACHINE WKS.
BLACK AND DECKER MFG. CO.
BLACKOR COMPANY
BLISS COMPANY, E. W.
BOTFIELD REFRACTORIES COMPANY
BRISTOL COMPANY
BROWN INSTRUMENT COMPANY
BUFFALO FORGE COMPANY
BUREAU OF POWER AND LIGHT (L. A.)

CALIFORNIA MALLEABLE CASTINGS CO.
CALIFORNIA OIL WORLD
CALORAC ELECTRIC CORPORATION
CAMPBELL, INC., A. C.
CANNEDY-OTTO MANUFACTURING CO.
CARBORUNDUM CO. (*Abrasives*)
CARBORUNDUM CO. (*Refractories*)
CENTRAL ALLOY STEEL CORPORATION
CHICAGO STEEL AND WIRE COMPANY
CHIKSAN OIL TOOL COMPANY, LTD.
CLARK TRUCTRATOR COMPANY

CLEVELAND TWIST DRILL COMPANY
CLIPPER BELT LACER COMPANY
COLONIAL STEEL COMPANY
COOPER HEWITT ELECTRIC COMPANY
CRUCIBLE STEEL CO. OF AMERICA
CUSHMAN CHUCK COMPANY

DALTON TOOL AND MACHINE CO.
DEARBORN CHEMICAL COMPANY
DINGS MAGNETIC SEPARATOR CO.
DISSTON & SONS, INC., HENRY
DUCOMMUN CORPORATION

EASON AND THEROLF TOOL CO.
EASTMAN KODAK COMPANY
ELECTRIC STEEL AND MFG. CO.
ELECTRICAL REFRACTORIES COMPANY
ELWELL-PARKER COMPANY

FEDERAL MACHINE AND WELDER CO.
FIRTH-STERLING STEEL COMPANY
FORD COMPANY, J. B.
FUSION WELDING CORPORATION

GAIRING TOOL COMPANY
GATHMANN ENGINEERING COMPANY
GENERAL ELECTRIC COMPANY
GLOBAR CORPORATION
GODDARD AND GODDARD COMPANY
GRANT MFG. & MACHINE CO.

HAGAN FURNACE CO., GEORGE J.
HALCOMB STEEL COMPANY
HARDINGE BROTHERS
HAYNES STELLITE COMPANY
HEPPENSTALL FORGE AND KNIFE CO.
HERBERTS MACHINE AND SUPPLY CO.
HISEY-WOLF MACHINE COMPANY
HORTON AND SON COMPANY, INC., E.
HOUGHTON AND COMPANY, E. F.
HUGHES TOOL COMPANY

JENSEN INSTRUMENT COMPANY
JOHNS-MANVILLE COMPANY
JOHNSON GEAR COMPANY
JORGENSEN COMPANY, EARLE M.

KAY-BRUNNER STEEL CASTING CO.
KELLEY REAMER COMPANY
KINNEY IRON COMPANY
KNAPP COMPANY, JAMES H.
KRUPP NIROSTA COMPANY, INC.

L. A. AUTOMOTIVE WORKS
LAIDLAW, WILLIAM, INC.
LANDIS MACHINE COMPANY
LARGENT COMPANY
LEEDS AND NORTHRUP COMPANY
LEITZ, INC., E.
LINCOLN ELECTRIC COMPANY
LINDE AIR PRODUCTS COMPANY
LUDLUM STEEL COMPANY

MACHINISTS TOOL AND SUPPLY CO.
MASTERTON AND COMPANY, JOS. A.
MCGILL METAL COMPANY
McLANATHAN AND SONS, F. W.
MERCO NORDSTROM VALVE COMPANY
MERIT OIL EQUIPMENT COMPANY
METTLER COMPANY, L. B.
MEYERS MACHINERY COMPANY
MINDER COMPANY, J. W.
MINERALS AND METALS CORPORATION
MORSE TWIST DRILL AND MACHINE CO.

NATIONAL TWIST DRILL AND TOOL CO.
NEW DEPARTURE MANUFACTURING CO.
NIAGARA MACHINE AND TOOL WORKS
NORMA BEARINGS COMPANY
NORTHWESTERN MANUFACTURING CO.
NUTTALL COMPANY, R. D.

OAKITE PRODUCTS, INC.
OIL AGE
O K TOOL COMPANY
OIL BULLETIN

PACIFIC ABRASIVE SUPPLY COMPANY
PACIFIC FACTORY
PANGBORN CORPORATION
PEERLESS MACHINE COMPANY
PEIR COMPANY, A. H.
PELS AND COMPANY, INC., HENRY
PENTON PUBLISHING COMPANY
PERFECT CASTER MANUFACTURING CO.
PERIN, IRA G.
PETROLEUM WORLD
PLOMB TOOL COMPANY

PUROX COMPANY

REED MANUFACTURING COMPANY
REGAN FORGE & ENGINEERING CO.
RHODES MANUFACTURING COMPANY
ROCKFORD MACHINE AND TOOL CO.
ROTOR AIR TOOL COMPANY

SAVAGE, W. J., COMPANY, INC.
SECURITY MANUFACTURING COMPANY
SHARPE MANUFACTURING COMPANY
SHRADER ELECTRIC COMPANY
SIDNEY MACHINE AND TOOL COMPANY
SIMONDS SAW AND STEEL COMPANY
SLATE AIRCRAFT CORPORATION
SLEEPER AND HARTLEY, INC.
SMITH BOOTH USHER COMPANY
SOUTHERN CALIFORNIA EDISON CO.
SOUTHERN CALIFORNIA GAS COMPANY
SOUTHERN CALIF. IRON & STEEL CO.
SPENCER TURBINE COMPANY
SPINDLER AND SAUPPE
STANDARD OIL COMPANY
STANDARD TOOL COMPANY
STEEL PUBLICATIONS
STERLING ELECTRIC MOTORS, INC.
STONE FOG LIGHT COMPANY
STOODY COMPANY
STORY COMPANY, C. S.
STRAND AND COMPANY, N. A.

TIMKEN STEEL AND TUBE COMPANY
TIMM COMPANY, O. W.

UNION DRAWN STEEL COMPANY
U. S. ELECTRICAL MFG. CO.

VANADIUM CORPORATION OF AMERICA
VEGETABLE OIL PRODUCTS COMPANY
VERNON FOUNDRIES
VICTOR WELDING EQUIPMENT CO.

WELDING ENGINEER PUBLISHING CO.
WEST COAST PIPE AND STEEL CO.
WESTERN AIR EXPRESS
WESTERN COLLEGE OF AERONAUTICS
WESTERN DROP FORGE COMPANY
WESTERN MACHINERY WORLD
WESTINGHOUSE ELECTRIC & MFG. CO.
WHITMAN BARNES-DETROIT CORP.
WHITNEY MANUFACTURING COMPANY
WILCOX COMPANY, E. A.
WILSON-MAEULEN COMPANY
WILSON WELDER AND METALS CO.
WISCONSIN ELECTRIC COMPANY, INC.

YOUNG BROTHERS COMPANY

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